British Columbia Emission Inventory of Nitrogen Oxides, Volatile Organic Compounds and Ozone (NO_x/VOC/O_3) as Greenhouse Gases

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CONTENTS

		Page
Acknowledgements		
Executive Summary		i
1.0	**Introduction**	1
2.0	**Methodology**	5
2.1	Data Management System	5
2.2	Literature Review	10
2.3	N_2O and NO_x Emission Sources	11
2.4	VOC Emission Sources	21
2.5	Ozone Inventory	23
3.0	**Results and Analysis**	25
3.1	Summary of NO_x, N_2O and VOC Emissions	26
3.2	Detailed NO_x and VOC Emissions by Sector	38
3.3	Detailed N_2O Emissions by Sector	48
3.4	Other Data Checks	54
3.5	Ozone Inventory	56
3.6	Gridded Summary of Emissions for B.C.	59
3.7	Analysis of Data Uncertainties	59
4.0	**Projected Inventory of NO_x/VOC/O_3 for the Year 2005**	66
4.1	Methodology	66
4.2	Results	68
4.3	Projected Changes in Ground-Level Ozone	71
5.0	**Management Measures**	72
5.1	Introduction	72
5.2	Overview of Comprehensive NO_x/VOC Plans	80
5.3	Specific NO_x/VOC Management Measures	88
5.4	Summary	110
6.0	**Discussion Conclusions**	114
6.1	Inventory Results	114
6.2	Management Measures	115
6.3	Conclusions	116
7.0	**Bibliography**	118
8.0	**Glossary**	123

CONTENTS (cont'd)

Appendix A: Residual Discharge Information System (RDIS)

Appendix B: Source Category / Industrial Sector Classification

Appendix C: Summary of the Methodologies Used to Calculate N_2O Emissions

Appendix D: NO_x/VOC/O_3 Greenhouse Gas Emission Inventory for B.C.: Major Source Emissions (by SCC)

Appendix E: Emission Forecasts for NO_x/VOC

Appendix F: B.C. EMPR Energy Demand Forecast Data

Appendix G: Summaries of Relevant Air Quality Management Measures

Appendix H: Alternative Fuels

Appendix I: Definition of CCME Management Measures

TABLES

		Page
Table 1	NO_x/VOC/O_3 Source Summaries	7
Table 2	Summary of NO_x/VOC Emissions for British Columbia (1985)	28
Table 3	Summary of NO_x/VOC Emissions as CO_2 Equivalents for British Columbia (1985)	32
Table 4	NO_x/VOC Emissions Forecast Summaries	70
Table 5	NO_x/VOC/N_2O Emissions by Sector (kt)	75
Table 6	Relative Emissions of NO_x/VOC/N_2O by Fuel Type	90
Table 7	Coverage of Road Transportation Measures	93
Table 8	Plan and SCAQMP Road Transportation Measures: CCME Management Plan	95
Table 9	Road Transportation Measures: Ontario Transportation Study	101
Table 10	Summary of Road Transportation Measures	102
Table 11	Other Management Measures	109
Table 12	Summary of NO_x/VOC/N_2O Management Measures	111

FIGURES

Fig. 1	Emission Inventory Grid for British Columbia	13
Fig. 2	Total NO_x/N_2O/VOC Emissions by Sector as CO2 Equivalents (1985)	34
Fig. 3	Total NO_x/N_2O/VOC Emissions as CO2 Equivalents (kilotonnes) (1985)	35
Fig. 4	Transportation NO_x/N_2O/VOC Emissions by Sector as CO_2 Equivalents (1985)	36
Fig. 5	Transportation NO_x/N_2O/VOC Emissions as CO_2 Equivalents (kilotonnes) (1985)	37

FIGURES (cont'd) **Page**

Fig. 6	Total NO_x Emissions by Sector (1985) (pie chartt)	39
Fig. 7	Total NO_x Emissions by Sector (1985) (bar graph)	40
Fig. 8	Total VOC Emissions by Sector (1985) (pie chart)	41
Fig. 9	Total VOC Emissions by Sector (1985) (bar graph)	42
Fig. 10	NO_x/VOC Emissions by Major Transportation Sector (1985) (bar graph)	43
Fig. 11	VOC Speciation of Biogenic Emissions From Vegetation (1985) (pie chart)	44
Fig. 12	NO_x/VOC Emissions by Major Industrial Processes (1985) (bar graph)	45
Fig. 13	NO_x Emissions by Major LOMEI Point Sources (1985) (bar graph)	46
Fig. 14	Total N_2O Emissions by Sector (1985) (pie chart)	50
Fig. 15	Total N_2O Emissions by Sector (1985) (bar graph)	51
Fig. 16	N_2O Emissions by Major Transportation Sector (1985) (bar graph)	52
Fig. 17	N_2O Emissions by Major Industrial Processes (1985) (bar graph)	53
Fig. 18	Summary of Biogenic NO_x/N_2O/VOC Emissions in B.C. as CO_2 Equivalents in kt/yr	60
Fig. 19	Summary of Anthropogenic NO_x/N_2O/VOC Emissions in B.C. (1985) as CO_2 Equivalents in kt/yr	61
Fig. 20	Summary of Emissions from Road, Offroad and Rail Transportation in B.C. as CO_2 Equivalents in kt/yr	77
Fig. 21	Summary of Emissions from the Pulp and Paper Industry in B.C. as CO_2 Equivalents in kt/yr	78

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EXECUTIVE SUMMARY

The sun's radiation, which is primarily in the visible and ultraviolet wavelength range, penetrates the earth's atmosphere through the ultraviolet filtering ozone layer in the upper atmosphere (stratosphere) and strikes the earth's surface. Some of this radiation is re-emitted from the earth's surface back into the atmosphere at somewhat longer wavelengths (in the infrared region of the electromagnetic spectrum). The greenhouse effect is the elevation in temperature of the atmosphere (and hence, the earth's surface) caused by the absorption of some of this infrared radiation from the earth by trace gases in the atmosphere. This phenomenon has maintained the surface temperature of the earth about 30°C above that which would otherwise exist and has thus made the earth suitable for habitation. The enhanced greenhouse effect is the anticipated increase in temperature above that achieved in the natural atmosphere (that is, before human development) caused by gases emitted from sources associated with human activities.

The Government of British Columbia is developing a comprehensive management strategy to reduce emissions of greenhouse gases in the province. The program, which is called The Greenhouse Gases Project, is to include the following groups of compounds which have been implicated as potential greenhouse gases:

- Nitrogen oxides (NO, NO_2 and N_2O), volatile organic compounds and ozone
- Chlorofluorocarbons and related gases
- Methane
- Carbon dioxide

This project, namely, the British Columbia Emission Inventory of NO_x/VOC/O_3 as Greenhouse Gases, addresses the first group of greenhouse gases identified above and was carried out under contract to the B.C. Ministry of Environment on behalf of the Greenhouse Gases steering committee. The fundamental objective of this study was two-fold:

1. Compilation of **NO_x/VOC/O_3 emission inventory**, and
2. Recommendation of **management measures** for reduction of NO_x/VOC/O_3.

NO_x/VOC/O_3 Emission Inventory

Consistent with the broad scope of strategy development for greenhouse gas management at this early stage, the NOx/VOC portion of the inventory was developed around the existing Environment Canada Residual Discharge Information System (RDIS) for base year 1985, since most of the information required was contained in RDIS. Similar data in the B.C. MOE/GVRD Lower Mainland Emission Inventory (LOMEI) allowed the preparation of an integrated inventory of these species for the Greenhouse Gases Project. The principal additions of new data to the existing RDIS/LOMEI databases were:

- Nitrous oxide (N_2O) from anthropogenic and biogenic sources, and
- VOCs from biogenic sources.

The study also involved identifying possible management measures, as well as evaluating them. The overall purpose was to assess which measures may be readily implemented/adopted and which may require more proactive actions by the provincial government.

Inventory Results

When the results of the inventory are expressed in terms of carbon dioxide equivalents, using the Global Warming Potentials given in an Intergovernmental Panel on Climate Change report, the total anthropogenic emissions of NO_x, N_2O and VOCs in B.C. are a minor fraction of the province's total CO_2 emissions. The total anthropogenic emissions of the gases inventoried for this project are about 7,300 kilotonnes per year (1985). NO_x, N_2O and VOCs make comparable contributions, and Transportation is the major contributor to these emissions (50%). These numbers are to be compared with CO_2 emissions for B.C. of 84,000 kilotonnes (1988). That is, the anthropogenic NO_x/VOC/O_3 emissions as greenhouse gases are equivalent to about 9% of the CO_2 emissions in the province. These results are summarized in the following table.

If the use of the Global Warming Potential factors developed by the Intergovernmental Panel on Climate Change is reliable (which has not been assessed), it appears that the gases inventoried for this project play a minor role as greenhouse gases.

SUMMARY of NO_x / VOC EMISSIONS as CO_2 equivalents for British Columbia (1985)

SOURCE	$NO_x(O_3)$[a] (kt)	N_2O (kt)	VOC (O_3)[b] (kt)	VOC (CO_2)[c] (kt)	Total (kt)
Anthropogenic					
1. B.C. Total	1854	2285	2276	854	7270
2. B.C. Total Industrial Processes [1]	333	276	471	177	1257
B.C. Industrial Processes	272	232	409	153	1066
B.C. Fuel Combustion	85	36	36	14	171
B.C. Transportation	1355	876	1024	384	3639
B.C. Incineration	18	125	19	7	169
B.C. Miscellaneous	63	142	699	262	1166
B.C. Open Sources [2]	0	0	27	10	37
3. LOMEI Industrial Point Sources	61	41	62	23	187
4. Fertilizer Application	0	96	0	0	96
5. Anaesthetics + Aerosols	0	43	0	0	43
6. Transmission Lines [3]	3	693	0	0	693

Notes

1 Includes BC Industrial Processes and LOMEI Industrial Point sources

2 Excludes forest fires which are considered to be a biogenic source

3 Major Transmission Lines are estimated to contribute minor amounts of ozone and NO_x (1-3 kT CO_2 equiv.) in addition to N_2O

a CO_2 equivalent of ozone produced from NO_x through atmospheric photochemistry

b CO_2 equivalent of ozone produced from VOC/NMHC through atmospheric photochemistry

c CO_2 produced from VOC/NMHC by atmospheric oxidation

SUMMARY of NOx / VOC EMISSIONS
as CO2 equivalents for British Columbia (1985) (Cont'd)

SOURCE	$NO_x(O_3)$[a] (kt)	N_2O (kt)	VOC (O_3)[b] (kt)	VOC (CO_2)[c] (kt)	Total (kt)
Biogenic					
1. B.C. Total Biogenic	355	11818	20578	7717	40468
2. B.C. Vegetation	0	0	20077	7529	27606
3. Soils	250	10196	0	0	10446
4. Forest Fires	81	151	500	189	921
5. Marine Waters	0	1456	0	0	1456
6. Lightning	24	17	0	0	41

Notes

a CO_2 equivalent of ozone produced from NO_x through atmospheric photochemistry

b CO_2 equivalent of ozone produced from VOC/NMHC through atmospheric photochemistry

c CO_2 produced from VOC/NMHC by atmospheric oxidation

CONCORD ENVIRONMENTAL

The global importance of CO_2 (estimated 61% of warming potential over 100 years) is about ten times that of NO_x, N_2O and VOCs combined (about 6% of warming potential over 100 years), according to an Intergovernmental Panel on Climate Change report. The data reported here imply that CO_2 is also about ten times as important as $NO_x/N_2O/VOC/O_3$ in B.C.

While the role of $NO_x/VOC/O_3$ as greenhouse gases is clearly much less than that of CO_2 itself, the importance of this issue to the development of the overall management strategy for anthropogenic emissions suggests that the validity of this approach based on Global Warming Potential be reviewed. The general consistency of the ozone emission quantity derived using both the Intergovernmental Panel on Climate Change approach and an alternate method of estimation with existing air quality data supports the validity of the approach.

Summary of Management Measures

The review of management measures was based on NO_x/VOC and general air quality plans in other jurisdictions.[1] The review of management measures focused on the largest source sectors for $NO_x/VOC/N_2O$: road transportation; off-road transportation; transmission lines; slash burning; kraft pulping. These five sources account for about 70% of total emissions in the Province. These results are summarized in the following table.

Because road transportation accounts for about 41% of provincial emissions, many of the most important management measures lie in this sector. For example, increased fuel efficiency standards, inspection and maintenance programs, and reduced gasoline volatility are the most promising measures identified in this review. All three have the potential to reduce emissions by more than 30 kilotonnes CO_2 equivalent annually, at relatively low cost and with few barriers to implementation. Collectively, these three measures could reduce emissions by about 225 kilotonnes per year (based on estimates for the Lower Fraser Valley). Other road transportation measures raise trade-offs between abatement potential and cost/barriers to implementation (including lifestyle changes).

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1 Detailed estimates of abatement potential and costs for B.C. was beyond the scope of this study. However, a concomitant study within the Greenhouse Gases Project has developed detailed estimates of road transportation measures from the perspective of CO_2 abatement.

Summary of NO_x/VOC/N_2O Management Measures

	Abatement Potential	Cost	Barriers to Implementation
Panel a) Road Transportation			
Gas volatility	H	L	L
Vehicle fuel efficiency	H	L/M[a]	L/M
Inspection & maintenance program	M/H	L	L
Restrictions on demand	H	M	H
Land use measures	H	L	L
Communications[a]	M	L	L/M
Increased transit use[a]	M	L	M
Traffic management[a]	M	L	M
Alternate fuels	NE	M	M/H
Public education	NE	NE	H
Panel b) Other Major Sources			
New standards for construction vehicles	L	NE	NE
Site analysis (slash burning)	NE	M	M
Design features (transmission lines)	NE	L	L
Process changes (kraft pulping)	H	H	H
New boiler standards (kraft pulping)	NE	L	NE
National NOx cap (rail transportation)	M[b]	NE	L/M
Panel c) Other Sources			
Reduced solvent use	L	L	
Public education re: solvents	NE	NE	
Industrial degreasing standards	L	L	
Dry cleaning standards	L	H	
Lower consumer surface coating	L	L	
Industrial surface coating standards	H	NE	
Vapour balancing & recovery A[c]	M	L	
Vapour balancing & recovery B[d]	M	H	
Petroleum & gas production	L	L/H	

Notes:

a At moderate levels of implementation

b National emissions reduction

c At gas storage & transfer depots and service stations

d During fuelling

Definitions:	Abatement	Cost
L = Low	<15kt CO_2 per year	< $300 per tonne
M = Moderate	15-30kt CO_2 per year	$300 - $700 per tonne
H = High	>30kt CO_2 per year	>$700 per tonne

Alternative transportation fuels have received considerable attention in the literature. However, based on the review conducted for this study, the overall effect on NO_x/VOC emissions is inconclusive; generally, VOC emissions appear to be lower for alternative fuels but NO_x emissions could be either higher or lower. The net effect is too unclear to recommend fuel switching as a management measure.

There is considerably more uncertainty surrounding management measures in other sectors. For example, a blanket policy to restrict slash burning is inappropriate given the variability of site characteristics in the Province; rather promotion of site-by-site analyses, with emissions reduction explicitly taken into account in silviculture prescriptions is suggested. Apart from NOx standards for industrial boilers, emissions reductions in kraft pulping may require significant process changes that could also have serious implications for markets and competitiveness. Further empirical work concerning the magnitude of N_2O emissions from transmission lines is called for, although cost and revenue concerns create incentives to reduce corona and line losses and, hence, N_2O emissions.

Additional emission reductions could be achieved through a variety of measures related to solvents, surface coatings and gas & diesel marketing, although some of these options are costly.

For those road transportation and other measures for which estimates were available, total abatement potential amounts to some 635 tonnes CO_2 equivalent per year, or less than 10% of total anthropogenic emissions of NO_x/VOC/O_3 in the Province.

As noted in the text, the list of possible management measures does not constitute a management strategy. In determining a strategy, NO_x/VOC measures must be considered within the context of other pollutants of concern. In some instances, there may be complementarity between measures, but in other cases, conflicts may arise. In some instances, cost-effectiveness may favour some measures over others. Another important aspect of a management strategy is to select the most appropriate policy tool or tools to implement the selected set of measures. These tasks will be part of the integration of all four components of the Greenhouse Gases Project.

Conclusions

There are several main conclusions to be drawn from the above discussion.

- The estimated contribution of the N_2O and O_3 documented in this inventory to the overall greenhouse gas emissions from sources in B.C. is a small fraction of the CO_2 emissions.

- NO_x and VOCs have about the same indirect global warming potential, apparently, so that the strategy for their control for other reasons, such as to reduce ground level ozone formation, is not influenced by their behaviour as greenhouse gases. In fact the strategies are complementary.

- N_2O contributes a minor portion of the overall greenhouse gas emissions in the $NO_x/N_2O/VOC/O_3$ inventory and is, therefore, of relatively minor importance for consideration of management measures.

- The previous conclusions suggest that the objectives of managing the $NO_x/VOC/O_3$ portion of the overall greenhouse gas issue are essentially congruent with those of NO_x/VOC management for control of peak ground level ozone levels (the National NO_x/VOC Management Plan). Some exceptions are noted in Chapter 5. Control of these gases will produce a "greenhouse bonus."

- When the abatement objectives of the NO_x/VOC Management Plan are expressed in terms of CO_2 equivalents, the collective contributions of the most probable reduction measures for anthropogenic emissions will be about 10% of the total greenhouse impact of the anthropogenic $NO_x/VOC/O_3$ emissions. This estimate includes both high and low cost options.

- The single most effective measures are that are known to have relatively low costs and low barriers to implementation lie in the road transportation sector. These measures include reduced gasoline volatility, tighter emission standards for motor vehicles, and an inspection and maintenance program for vehicles.

- It is obvious, but bears repeating, that all of the possible management measures for $NO_x/VOC/O_3$ as greenhouse gases must be considered in the context of the management measures for the other classes of greenhouse gases, especially CO_2, and also in the context of the National NO_x/VOC Management Plan.

1.0 INTRODUCTION

Background

The Government of British Columbia is developing a comprehensive management strategy to reduce emissions of greenhouse gases in the province. The program, which is called The Greenhouse Gases Project, is to include the following groups of compounds which have been implicated as potential greenhouse gases:

- Nitrogen oxides, volatile organic compounds and ozone
- Chlorofluorocarbons and related gases
- Methane
- Carbon dioxide

The strategy for each group of greenhouse gases is being overseen by a steering committee. The lead ministry for the overall project is the Ministry of Environment, and representatives of the following ministries or agencies sit on the four committees:

Ministry of Environment (MOE)
Ministry of Solicitor General (Motor Vehicle Branch)
Ministry of Transportation & Highways
Ministry of Energy, Mines & Petroleum Resources (EMPR)
Ministry of Health
Ministry of Tourism
Ministry of Municipal Affairs, Recreation & Culture
B.C. Transit
Greater Vancouver Regional District (GVRD)

This project addresses the first group of greenhouse gases shown above: nitrogen oxides, volatile organic compounds and ozone. It has been carried out under contract to the B.C. Ministry of Environment acting on behalf of the participating ministries by Concord Environmental Corporation and The ARA Consulting Group Ltd.

Nitrogen oxides and volatile organic compounds are related to ozone as precursors involved in the production of ozone through atmospheric chemical reactions. Ozone is not emitted directly from anthropogenic (manmade) or biogenic (natural sources) in appreciable quantities.

Some of the common definitions of the above groups overlap, therefore, for the purposes of this project, the following restricted definitions were adopted, to avoid redundancy. "Nitrogen oxides"

have been taken to comprise nitric oxide (NO) and nitrogen dioxide (NO_2) - which are normally aggregated as NO_x - and nitrous oxide (N_2O). "Volatile organic compounds" (VOCs) excludes the following groups which would otherwise be included normally: chlorofluorocarbons and related chlorinated, fluorinated and brominated compounds. The remaining compounds in this group are often referred to as non-methane hydrocarbons (NMHCs), and these compounds are of primary interest in this project. Methane is normally not included in the definition of VOCs. These restrictions avoid conflict with the second and third projects on the above list.

The mandate of the NO_x/VOC/O_3 inventory was to integrate and consolidate data from existing inventories wherever possible, not to develop new data where existing data would be adequate. Consistent with the broad scope of strategy development for greenhouse gas management at this early stage, it was decided to develop the NO_x/VOC portion of the inventory around the existing Environment Canada Residual Discharge Information System (RDIS) for the base year 1985, since most of the information which was required was contained in RDIS. This inventory has been compiled primarily in support of ground level ozone control programs, but the data are equally applicable to the current requirement. Similar data in the B.C. MOE/GVRD Lower Mainland Emission Inventory (LOMEI) allowed the preparation of an integrated inventory of these species for the Greenhouse Gases Project.

The principal additions of new data to the existing RDIS/LOMEI databases were

- nitrous oxide (N_2O) from anthropogenic and biogenic sources, and
- VOCs from biogenic sources.

Several new emission sources for some of the compounds were added to the database, but these are a minor part of the emissions.

Scientific Background

A brief discussion of the greenhouse gas issue appears in a background paper prepared for the B.C. Round Table on the Environment and the Economy (Concord, 1990). The following table taken from that report summarizes the current understanding of the roles of the various gases.

A more detailed discussion of the state-of-science with respect to the roles of the greenhouse gases appears in a report by the Intergovernmental Panel on Climate Change (IPCC) of the World

Characteristics of Greenhouse Gases

Greenhouse Gas	Concentration: Present (1990) [ppb]	Concentration: Trend [%/y]	Concentration: Projected 2025 [ppb]	Radiative Forcing Relative to CO_2*	Lifetime** [y]	Contribution to Greenhouse Warming in the 1980's [%]	Anthropogenic Sources
Carbon dioxide (CO_2)	353,000	0.5	450,000	1 (1)	120	55	fossil fuels; deforestation; respiration
Methane (CH_4)	1,720	0.9	2060	21 (58)	7-10	15	livestock; anaerobic decay; fuel losses
Nitrous oxide (N_2O)	310	0.25	375	206 (206)	150	6	microbial action on fertilizers; fossil fuels & biomass burning
Chlorofluorocarbons:							
CFC-11 (CCl_3F)	0.3	4	1.1	12,400 (3,970)	65	24	refrigerants; degreasers; foaming agents
CFC-12 (CCl_2F_2)	0.5	4	1.8	15,800 (5,750)	130		
Tropospheric ozone (O_3)	10-300	~1	+10%	2,000 (1,800)	0.2	?***	sunlight acting on NO_x/VOCs

Notes: * Relative effectiveness on a molecule-for-molecule basis. Number in parentheses is effectiveness based on mass. Ozone effectiveness is from CO_2/Climate Report: 90-01, all others from IPCC (1990).

** Lifetime is the persistence based on the net result of all production and removal processes.

*** May be about 10% (others to be reduced proportionately)

Sources: CO_2/Climate Report: 90-01 and IPCC, 1990.

Meteorological Organization and the United Nations Environment Program (IPCC, 1990). The data in the IPCC report and the above table indicate that of the compounds being covered by this portion of the inventory project (NO_x/VOC/O_3), NO_x (through the production of ozone) and N_2O are thought to be the most significant contributors to potential greenhouse effects. The IPCC study estimates that N_2O will contribute about 4% of the total effect integrated over 100 years and NO_x

about 1%. IPCC also estimates that VOCs [as non-methane hydrocarbons (NMHCs)] will contribute 0.5% of the total effect. These impacts of NO_x and VOCs are calculated on the basis of their contribution to the formation of ground level ozone, which is the radiatively-active (greenhouse) gas of interest. VOCs also contribute a small amount to CO_2 formation. N_2O is a greenhouse gas in its own right.

The chemistry of the atmosphere is very complex, and the models by which the indirect effects of NO_x and VOCs have been estimated do not take into account all possible effects. Such estimates, then, are qualitative at best.

Organization of the report

The report begins with a detailed presentation of the methodology used to develop the database (Chapter 2). This is provided so that those wishing to use or update the database itself will be able to see, in conjunction with Appendix C, how the RDIS/LOMEI databases were adapted to produce the integrated database for the whole province. Those readers who are interested primarily in the results and interpretation of the database need not concentrate on this chapter.

Chapter 3 presents detailed data and analysis of the inventory. All of the results are presented in graphic format, with explanatory material only in the text. The principal implications of the inventory results can be found in the figures.

Chapter 4 presents a projection of the inventory results to the year 2005 and describes the basis for the projection. This information provides the basis for the discussion of management measures, which follows in Chapter 5.

The report text concludes with discussion and conclusions of the principal findings of the inventory and management measures evaluation (Chapter 6). Chapter 7 lists references and relevant literature.

2.0 METHODOLOGY

2.1 Data Management System

An analysis of existing emission inventories and data management systems was carried out to identify a database management system most suited for compiling the B.C. NO_x/VOC/O_3 Greenhouse Gases Inventory. Systems were evaluated on the basis of compatibility, accessibility, data completeness and ease of use. The system chosen for this study was Environment Canada's Residual Discharge Inventory System (RDIS) in which the 1985 National Emissions Inventory System is currently stored (Environment Canada, 1990).

RDIS is a dBase IV-supported database management system in which emissions from the following anthropogenic point, area and mobile sources in B.C. (1985) are stored:

- Industrial Processes
- Fuel Combustion
- Transportation
- Incineration
- Miscellaneous
- Open Sources (including forest fires)

Specific industry sectors and associated Standard Industrial Classification (SIC) codes for the above sources are listed in Appendix B.

Concord used RDIS rather than developing a separate inventory system starting from basic principles or other existing inventories for the following reasons:

- data completeness - Both anthropogenic NO_x and speciated VOC emission inventories for B.C. are contained in RDIS. The B.C. 1985 Point Source Emission Inventory was incorporated into RDIS.

- reporting capabilities - RDIS is capable of resolving and reporting data in both spatial (standard 127 km x 127 km grid) and in temporal (hourly, daily, annually) formats.

- data manipulation - Being in the familiar dBase (IV or III Plus) format, RDIS can be manipulated to include additional contaminants such as N_2O, as well as additional source sectors. RDIS is also capable of speciating VOCs. Since U.S. EPA Source Classification Codes (SCCs) are a functional part of the database, input of EPA's commonly accepted emission factors is straightforward.

- compatibility - Since RDIS contains the National Emissions Inventory System, it is beneficial to ensure the compatibility of other Canadian emission inventories with this database.

- accessibility - A Runtime version of the most up-to-date RDIS, as well as the (updated and corrected) 1985 emission inventory for B.C., was provided to Concord Environmental for this study. A significant amount of Environment Canada staff time and technical resources were also made available to Concord.

The National Emissions Inventory System is evolving and is expected to be further refined with an update planned for the 1990 base year. The emphasis of the current project was more on compiling emission data from sources and for contaminants (greenhouse gases) not presently included in RDIS and less on updating anthropogenic NO_x (excluding N_2O) and VOC emission sources for base year 1985. These sources are already included in RDIS for the most part.

The Greenhouse Gases Inventory includes both anthropogenic and biogenic sources of N_2O, NO_x and VOC. Environment Canada is currently integrating the (spatially) more highly resolved 1985 Lower Mainland Emissions Inventory (LOMEI) into RDIS, although the process has not been completed at the time of this study. As a result, an effort was made to incorporate relevant data from LOMEI with the assistance of GVRD staff. Finally, although updating existing data was not an intentional component of this study, an effort was made to identify and correct, in cooperation with Environment Canada staff, a number of data deficiencies and errors which became apparent while working with the RDIS database system.

A summary of NO_x/VOC/O_3 emission information sources and extent of integration into the RDIS inventory is provided in Table 1. The following is a description of the methodologies used in compiling the B.C. NO_x/VOC/O_3 Greenhouse Gases Inventory using RDIS.

Table 1. NO_x/VOC/O_3 Source Summaries

Parameter	Source	Data Source	Method
NO_x	*Anthropogenic*		
	B.C. Point Sources	RDIS[1]	Update RDIS
	B.C. Mobile Sources	RDIS	Update RDIS
	B.C. Area Sources	RDIS	Update RDIS
	LOMEI[2] Point Sources	LOMEI (1985)	Integrate into RDIS
	LOMEI Mobile Sources	LOMEI (1985)	Used as data check only
	LOMEI Area Sources	LOMEI (1985)	Used as data check only
	Biogenic		
	Soils	Environment Canada (1981) Farley (1979)	Gridded Summary
		Agriculture Canada (1991)	Used as data check only
		Environment Canada (1981)	Used as data check only
N_2O	*Anthropogenic*		
	B.C. Point Sources	RDIS/Emission Factors (EF) (Env Can 1991*a*)	Integrate into RDIS
	B.C. Mobile Sources	RDIS/EF (Environment Canada 1991*a*) MOBILE 4 (Environment Canada 1991*b*)	Integrate into RDIS
	B.C. Area Sources	RDIS/EF (Environment Canada 1991*a*)	Integrate into RDIS
	LOMEI Point Sources	LOMEI/EF (Environment Canada 1991*a*)	Integrate into RDIS
	Fertilizer Application	RDIS/EF (Industry Statistics)	Gridded Summary
	Slash/Biomass Burning	RDIS/EF (Environment Canada 1991*a*)	Integrate into RDIS
		EMPR[3] (1990)	Used as data check only
	Human Waste	Literature/EF	No data

CONCORD ENVIRONMENTAL

Table 1 (cont'd). NO_x/VOC/O_3 Source Summaries

Parameter	Source	Data Source	Method
	Animal Waste	Literature/EF	No data
	Ammonia Manufacture	RDIS/EF	No data
	Nitric Acid Manufacture	RDIS/EF	No data
	Nylon Manufacture	RDIS/EF	No data
	Anaesthetics/Aerosols	U.S. Production Data (OME[4] 1991)	Gridded Summary
	Water Treatment	Literature/EF	No data
	Transmission Lines	B.C. Hydro/EF (Hill 1984)	Gridded Summary
	Biogenic	see biogenic NOx above	Integrate into RDIS
VOC	*Anthropogenic*		
	B.C. Point Sources	RDIS	Update RDIS
	B.C. Mobile Sources	RDIS	Update RDIS
	B.C. Area Sources	RDIS	Update RDIS
	LOMEI Point Sources	LOMEI (1985)	Integrate into RDIS
	LOMEI Mobile Sources	LOMEI (1985)	Used as data check only
	LOMEI Area Sources	LOMEI (1985)	Used as data check only
	Petroleum Refining & Gasoline Marketing	RDIS	Update RDIS
		LOMEI (1985)	Used as data check only
		CPPI[5] (1991)	Used as data check only
	Biogenic		
	Vegetation (speciated)	Environment Canada (1989)	Gridded Summary
		LOMEI (1985)	Used as data check only

Table 1 (cont'd). NO_x/VOC/O_3 Source Summaries

Parameter	Source	Data Source	Method
VOC	Forest Fires	RDIS LOMEI (1985)	Update RDIS Used as data check only
Ozone (O_3)	*Anthropogenic/Biogenic*	BC MOE[6]/IPCC[7]	Provincial Summary

1 Residual Discharge Information System
2 Lower Mainland Emission Inventory
3 Energy Mines & Petroleum Resources
4 Ontario Ministry of the Environment
5 Canadian Petroleum Products Institute
6 British Columbia Ministry of Environment
7 Intergovernmental Panel on Climate Change

CONCORD ENVIRONMENTAL

2.2 Literature Review

The emphasis of an extensive review of the literature was to identify generally accepted emission factors and inventory methodologies for the following:

- anthropogenic N_2O
- biogenic N_2O
- biogenic NO_x
- biogenic VOCs (speciated)
- radiatively active VOCs
- O_3 emission inventories

In general, most of the current greenhouse gas literature addresses the above topics only in the context of global greenhouse gas budgets and, therefore, provides little information on source-specific emission factors. Nevertheless, emission information for the most significant source sectors, however dated, has been uncovered and a number of interesting related findings have been noted. For example, in 1988 it was concluded that current existing N_2O emission factors from fossil fuel combustion were over-estimated by at least an order of magnitude due an inherent error in the prescribed sampling methodology (Montgomery et al, 1989; Kokkinos, 1990; Wilson, 1990).

It is now thought that emissions of N_2O from fossil fuel combustion sources are only 1-5% of NO_x emissions, instead of the 20-25% estimated by earlier studies. Currently accepted N_2O emission factors for the combustion of various fossil fuels, as provided by Environment Canada 1991b), were relied on for this study.

A number of studies on behalf of Environment Canada, both current and dated, have attempted to quantify, on a national or provincial scale, nitrogen and organic compound emissions from biogenic sources. A number of these inventories employed methodologies similar to those used by regulatory agencies in the U.S. attempting to quantify biogenic emissions for input into urban airshed and regional models. Similar emission factors and methods were used in this emission inventory.

No references were found which addressed VOCs specifically as radiatively-active greenhouse gases. For the purposes of this study, VOCs are defined essentially as non-methane hydrocarbons

(NMHC), since other compounds normally included in this class (such as, chlorofluorocarbons, methane and chlorinated solvents) are being addressed by other studies in the current group of greenhouse gas emission inventories for B.C.

However, in a recently published Intergovernmental Panel on Climate Change document (IPCC, 1990), not one of the most important direct-acting greenhouse gases was listed in the non-methane hydrocarbon class of VOCs (IPCC, 1990, Table 2.8). IPCC (1990) does, however, estimate the indirect greenhouse gas impact of NMHCs as precursors of O_3. This suggests that VOCs have been addressed as potential, direct greenhouse gases, but have not been considered to be significant as such. In the current study, VOCs are addressed as indirect greenhouse gases as ozone precursors and, to a lesser extent, as CO2 precursors.

The methodologies used in compiling the Greenhouse Gases Inventory are described in some detail in Appendix C, so that those using the database can trace modifications to the basic RDIS and LOMEI systems, and will be able to update the results reported here when newer data become available.

2.3 N_2O / NO_x Emission Sources

As described earlier, Environment Canada source sectors are grouped according to the following classification scheme:

- Industrial Processes
- Fuel Combustion
- Transportation
- Incineration
- Miscellaneous
- Open Sources

A more detailed breakdown of each of these sectors by Standard Industrial Classification code (SIC) is provided in Appendix A. In the following, source emission categories which are formally identified in the inventory are written with capital letters, for example, Fuel Combustion, Heavy Duty Diesel Trucks, etc. to distinguish them from generic counterparts.

2.3.1 *ANTHROPOGENIC N_2O SOURCES*

In developing the anthropogenic N_2O emission inventory for B.C., the following three fundamental assumptions were made:

- All sources, with noted exceptions, emit predominantly as a consequence of fossil fuel combustion processes which can be described by Source Classification Codes (SCCs).
- N_2O emissions occur where there are also NO_x emissions, again, with noted exceptions.
- N_2O emissions are uncontrolled.

Currently, N_2O emission factors exist for fossil fuel combustion processes using gasoline, diesel, coal, oil, natural gas or fuel wood. Within RDIS, it is possible to link industry-specific SIC codes with process-specific SCC codes. By including a contaminant code specifically for N_2O within RDIS, it was possible, given the above assumptions, to determine N_2O emissions from anthropogenic sources making use of the unique plant, proration, spatial, and temporal resolution parameters already existent within RDIS.

N_2O emissions were put on the standard 127x127 km^2 grid used for emission inventories in Canada and totalled for each of the eighty grid squares covering the province. The grid used is shown superimposed on a map of B.C. in Figure 1.

The underlying philosophy behind all data manipulation was to ensure method consistency and ease of use when future national (or provincial) emission inventories are to be updated using more accurate data and emission estimation techniques. More on the N_2O emission estimation methods applied appears in the following sections and in Appendix C.

2.3.1.1 INDUSTRIAL PROCESSES / FUEL COMBUSTION SOURCES

N_2O emissions from stationary combustion sources were estimated using N_2O emission factors from Environment Canada (1991b) for the following fuels:

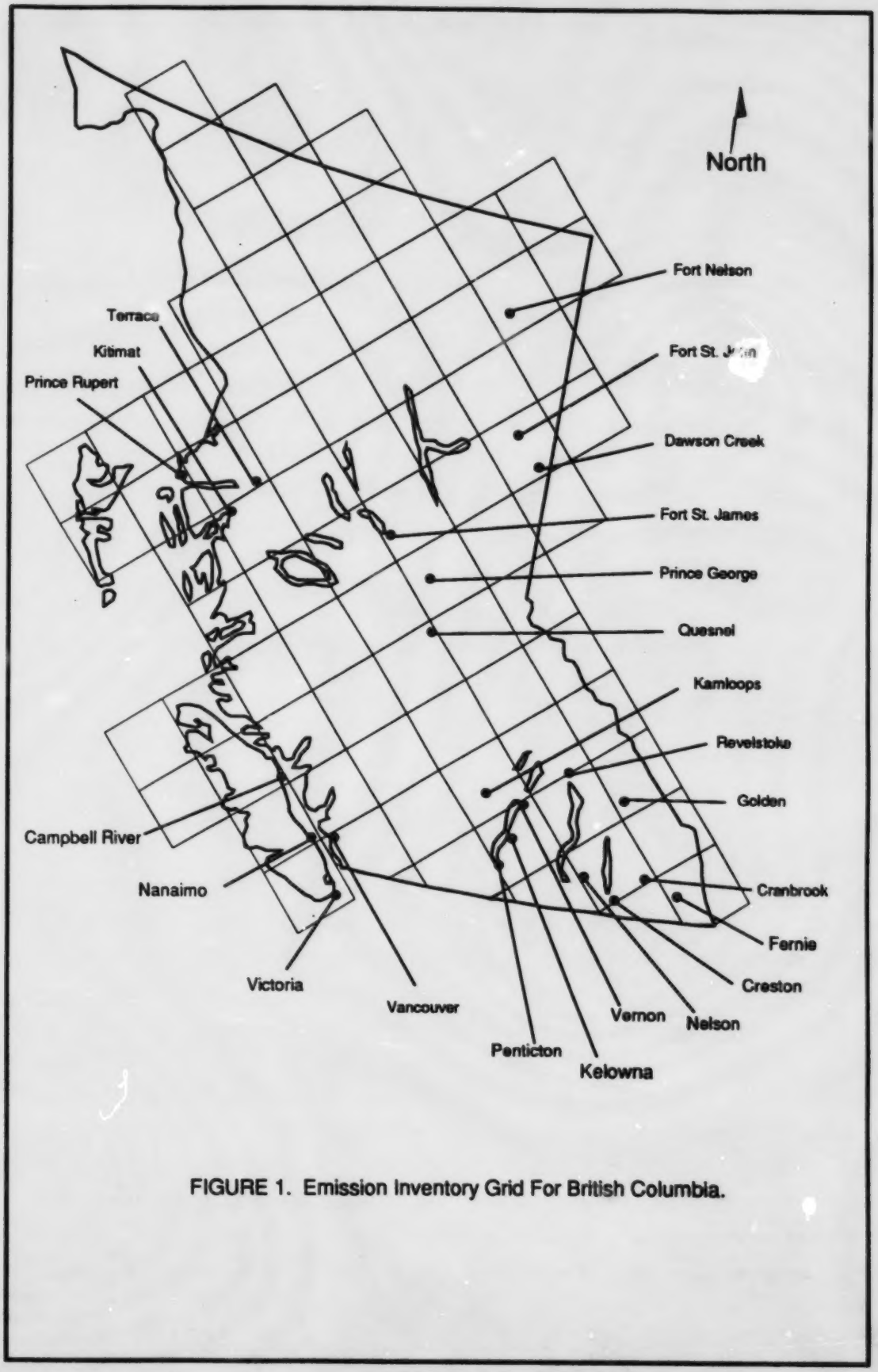


FIGURE 1. Emission Inventory Grid For British Columbia.

- Natural Gas
- Light and Heavy Oil
- Coal (conventional)
- Wood Combustion

These fuels are listed here in ascending order in terms of emissions on an energy equivalency basis, with natural gas producing the least N_2O per unit fuel energy content and wood fuel producing the largest emissions per unit fuel energy content. For a combustion process, the application of these emission factors is straightforward, once the type of fuel burned and the fuel units have been identified. However, where only production quantities (e.g. air dried pulp produced, coal dried, gas compressed, ore mined, etc.) rather than fuel quantities were given in RDIS, N_2O emission factors were determined by assuming that $N_2O_{\text{production based}}/N_2O_{\text{fuel based}}$ emission ratios were equivalent to $NO_{x\ \text{production based}}/NO_{x\ \text{fuel based}}$ emission ratios for similar source types. Since NO_x production-based emission factors as well as fuel-based emission factors were given, the above equation can be solved for a $N_2O_{\text{production based}}$ emission factor. Many sources were characterized by both a production quantity and a fuel quantity: e.g., recovery boilers and lime kilns in the pulp and paper industry are characterized by the amount of air dried pulp produced, as well as supplemental oil or natural gas fuel used. In these cases, only the N_2O emissions of the fuel combustion part of the process could be calculated.

Detailed examples and a discussion of the deficiencies of the approach used may be found in Appendix C.

Fuel Combustion sources within RDIS are considered as area sources. This means that RDIS spatially distributes these sources throughout the province using prorating parameters such as population, commercial / industrial labour force and residential dwelling units. For consistency, N_2O emissions from fuel combustion sources within the Lower Mainland were determined using RDIS by summarizing appropriate SICs from the Lower Mainland grid square.

A comparison of the RDIS emission estimates for Fuel Combustion sources with those presented in GVRD (1988a) appears in the results section (Section 3) of this report.

Nylon Manufacturing, Nitric Acid Manufacturing and Ammonia Manufacturing have each been cited in recent literature as being potentially significant sources of N_2O. In particular, it is estimated that N_2O emissions from Nylon Manufacturing may account for up to 10% of recent global

increases in ambient N_2O (Thiemens et al, 1991). A search for appropriate SIC and SCC codes in both RDIS and LOMEI indicated that there are no Nylon Manufacturing or Nitric Acid Manufacturing facilities in B.C. Ammonia is currently being produced at the Ocelot Chemicals Ltd. facility at Kitimat , B.C. and by Cominco Fertilizers Ltd. in Trail, B.C. However, since no N_2O process-based emission factors could be found in the literature, N_2O emissions from this plant were estimated only for the fuel combustion part of the process.

2.3.1.2 LOMEI INDUSTRIAL POINT SOURCES

As mentioned previously, Environment Canada and Greater Vancouver Regional District (GVRD) staff are currently integrating the 1985 Lower Mainland Emission Inventory (LOMEI) into RDIS. Therefore, only an incomplete number of point sources located in the Lower Mainland is contained in RDIS. Thus, it was necessary to delete this set of data from the existing RDIS database to avoid redundancies when the complete set of $NO_x/N_2O/VOC$ emissions data from the Lower Mainland was reintegrated into RDIS in a consistent manner.

A cartographic analysis of the province suggests that the Lower Mainland, as defined in the 1985 LOMEI Summary Report (GVRD, 1988a), essentially encompasses one complete 127x127 km^2 grid square (in the following referred to as the Lower Mainland grid square). In addition, a comparison of population data for the Lower Mainland grid square, as assigned by RDIS, with census data used for LOMEI (Statistics Canada, 1987), suggests that the two areas are similar. Although the grid overlay is not a perfect fit, it is estimated that potential emission redundancies or deficiencies which may result will be minor, since all major population centres within the Lower Mainland are included in this grid square.

Complete point source industry sectors from LOMEI, including Non-metallic Minerals, Wood Industries, Paper & Allied, and Other Industries also exist in RDIS, but as area sources. As a consequence of being input into RDIS as area sources, however, emissions from each of these sectors, instead of being assigned solely to the Lower Mainland grid square, are distributed throughout the province as a function of population. This results in an inaccurate distribution of anthropogenic emissions in B.C. These sources were also deleted from RDIS.

RDIS's griding utility was then performed without the above emission sources. Emissions in the Lower Mainland grid square were subsequently summarized by SIC and contributions from Industrial Processes and Other Industrial Fuel Combustion remaining in the grid were rationalized

and adjusted appropriately.

An electronic summary of LOMEI 1985 point sources was provided by GVRD. The NO_x emissions in this file account for 97.3% of the Lower Mainland NO_x emissions reported in the 1985 LOMEI point source summary report (GVRD, 1988d), so that the inventory is considered essentially complete. Using this data, we calculated N_2O point source emissions as a percentage of NO_x emissions. The applied methodology is described in Appendix C.

2.3.1.3 TRANSPORTATION SOURCES

It is estimated that world vehicular emissions represent 3.3% of manmade N_2O emissions, or 0.2% of the calculated global greenhouse gas contribution (Dasch, 1991). However, an important finding during the review of N_2O emission literature was that N_2O emissions from vehicles with catalytic converters are greater than N_2O emissions from vehicles without catalytic converters (Dasch, 1991). These findings were confirmed from comprehensive study programs undertaken on behalf of the U.S. Environmental Protection Agency (EPA) in which emission factors were determined for various vehicle and catalytic converter types. The emission factors used for this study were provided by Environment Canada (1991b) and are listed in Appendix C.

These factors are similar, although not identical, to the U.S. EPA's emission factors. Using existing NO_x data from RDIS and the mentioned N_2O emission factors, the ratios of N_2O/NO_x vehicle emissions calculated in this study were similar to the N_2O/NO_x emission ratios determined experimentally in the EPA study.

RDIS contains the following base quantities for the Transportation sector:

- number of movements for aircraft
- number of vehicles for most vehicle categories
- amount of diesel burned for diesel vehicles

In addition, Environment Canada provided the breakdown of catalytic converter use by vehicle category for the years 1985 and 2005 using the U.S. EPA model MOBILE 4 (1991c), and average vehicle kilometres travelled (VMT) and fuel consumption data were obtained from Statistics Canada. These data were used to calculate the N_2O emissions of Vehicles. N_2O emissions from Aircraft were estimated using average fuel consumption factors obtained from U.S. EPA AP-42

(EPA, 1985) for one representative aircraft type in each aircraft class. Given the similar properties of the two fuels, diesel fuel was used as a surrogate for aviation fuel, so that the N_2O emission factor for diesel fuel combustion could be used. N_2O emissions from Rail Traffic and Other Diesel Vehicles (Light Duty Vehicles) were estimated by applying the emission factors to the base fuel quantities contained in RDIS. N_2O emissions from Marine traffic and Off-Road Gasoline categories could not be estimated due to nonexistent or inappropriate base quantity data. Given the low emission factors for non-catalytic and diesel combustion sources, the error introduced by these omissions is considered to be negligible.

Neither base quantity data nor total emission estimates from natural gas powered vehicles are listed in RDIS. Since the gas-powered fleet in 1985 is relatively small and therefore a minor contributor to the inventory, it was not considered in this study. As the fleet size continues to grow, however, its contribution to future inventories may be considerably more significant.

Again, for consistency, N_2O emissions from Transportation sources in the Lower Mainland grid square were determined using RDIS. A comparison of RDIS Transportation source emission estimates with those presented in the LOMEI 1985 Mobile Sources Summary Report (GVRD, 1988b) appears later in this report.

A more detailed description of the methodology used to estimate N_2O emissions from transportation sources may be found in Appendix C.

2.3.1.4 INCINERATION / MISCELLANEOUS / OPEN SOURCES

RDIS was also used to estimate N_2O emissions from these area source categories using existing RDIS NO_x data, as well as fossil fuel-based N_2O emission factors. The methods employed were similar to those used to provide estimates of anthropogenic N_2O emissions from the area source categories Industrial Processes and Fuel Combustion, as described above. Estimates from LOMEI 1985 Area Sources Summary Report (GVRD, 1988c) were used for comparison (see section 3.4).

It has been suggested that significant N_2O emissions may occur during gasification processes resulting from increased nitrogen runoff during forest clearing activities (Bowden and Bormann, 1986). In general, however, given the level of uncertainty which already exists by using current N_2O emission factors and emission inventory methodologies (for both biogenic and anthropogenic sources), the error contributed by not considering this parameter is considered to be negligible.

Several of the largest sources of N_2O from these sectors include Wood Waste Incineration and Slash Burning. It is estimated that approximately 7% of global N_2O emissions can be attributed directly to the burning of biomass (Coffer et al, 1991). N_2O estimates for the Greenhouse Gases Inventory were determined using the emission factor for wood combustion input to RDIS. A comparison of Slash Burning and Wood Waste Incineration base quantities with those presented in the Carbon Dioxide Inventory for B.C. (EMPR, 1990) appears in section 3.4. High voltage Transmission lines and the Application of Nitrogen Fertilizers have each been identified as potentially significant sources of N_2O.

N_2O emissions from Transmission Lines, estimated using a method described by Hill et al (1984) (see Appendix C), are a function of line voltage, line loss, and line length. Average line losses and transmission lengths were obtained from B.C. Hydro (1991a), and transmission corridors for major systems (i.e., greater than 138 kV circuit) were identified from a B.C. Hydro survey map (1990). Given the length of B.C. Hydro's transmission system, emissions of N_2O from this source were found to be appreciable (see Chapter 3).

N_2O emissions from Fertilizer Application have been found to vary between 0% and 1.5% of the nutrient nitrogen applied and are highly dependent on the fertilizer type and a variety of natural factors (Eichner, 1990). The emissions are estimated to account for 2.3-2.7% of the global source of N_2O (McElroy and Wofsy, 1985). For the purposes of this study, it was assumed that N_2O emissions were 1.2% of the nutrient nitrogen applied (Environment Canada, 1991b; Anderson et al, 1987; Eichner, M., 1990; Conrad et al, 1983). Data on fertilizer applied in B.C. were provided by the Western Canada Fertilizer Association (1991). Because of limited available information, these fertilizer-based N_2O emission estimates do not include potential emissions resulting from the application of manure.

Separate gridded summaries for N_2O emissions were determined for each of the above sources.

N_2O emissions from Anaesthetics and Aerosol use were estimated using U.S. N_2O production data (Ontario Ministry of the Environment, 1991). Production data was prorated based on population (the population of B.C. is approximately 1% that of the U.S.) to estimate emissions of N_2O from these sources. It is assumed, therefore, that Canadian production (and use) quantities are proportional to population and that they are released completely to the atmosphere each year.

Limited information regarding N_2O emissions from either Waste Water Treatment processes or Human/Animal Waste was found in the literature. One source suggests that Human Wastes could provide a global source of N_2O of between 2% and 15% of the rate at which the gas is consumed photochemically today in the atmosphere (Kaplan et al, 1978). Contributions from Animal Wastes may exceed those of Human Wastes by a factor of three. However, specific emission factors relating emissions of N_2O to these sources could not be found in the literature, and, consequently, no N_2O emission estimates were provided for these sources.

The single largest open source of N_2O and NO_x was found to be Forest Fires. For the purpose of this study however, Forest Fires are considered to be biogenic emission sources and are addressed below.

2.3.2 *ANTHROPOGENIC NO_x SOURCES*

For the purposes of this study, it was assumed that anthropogenic NO_x emission sources currently compiled in RDIS for the 1985 base year are essentially complete. Only minor modifications were made to the databases, in cooperation with Environment Canada staff, where updates and data input errors required necessary changes. NO_x emissions were again put on the standard 127x127 km^2 grid and totalled for each of the eighty grid squares covering the province (Figure 1).

For consistency, NO_x emissions from Fuel Combustion sources within the Lower Mainland were determined using RDIS by summarizing appropriate SICs from the Lower Mainland grid square. A comparison of the RDIS emission estimates for Fuel Combustion sources with those presented in GVRD (1988a) appears in the results chapter (Chapter 3) of this report.

NO_x emissions from Transportation sources were taken directly from the RDIS databases, and NO_x emissions in the Lower Mainland were also determined using RDIS. A comparison of RDIS Transportation source emission estimates with those presented in the LOMEI 1985 Mobile Sources Summary Report (GVRD, 1988b) appears later in this report.

NO_x emissions from Lower Mainland Industrial Point sources were taken from an electronic summary provided by GVRD.

Slash Burning and Wood Waste Incineration emissions were taken from RDIS and the base quantities compared with those presented in the Carbon Dioxide Inventory for B.C. (EMPR,

1990). See section 3.4 for details.

2.3.3 *BIOGENIC N_2O AND NO_X SOURCES*

N_2O and NO_x emission estimates were determined for the following biogenic emission sources:

- Soils
- Forest Fires
- Lightning
- Marine Waters

2.3.3.1 SOILS

N_2O and NO_x emissions from soils occur as a result of both nitrification and denitrification processes. Although numerous studies have been undertaken in an attempt to quantify emission fluxes from soils, given the highly variable soil parameters such as temperature, soil type, moisture content, etc., a wide range of N_2O/NO_x emission factors has been estimated (Mosier et al, 1981; Bowden et al, 1990).

Although dated and generalized, emission factors obtained from Environment Canada (1981b) appeared to be the most complete and were used for this study. These factors approximate the yearly average flux of N_2O and NO_x per soil order and were derived using a method incorporating average monthly soil temperatures (for months with an average air temperature $\geq 4^{\circ}$ C) and the estimated biological activity. Given that these flux estimates have been used to estimate Canada-wide N_2O and NO_x emissions, and thus do not refer explicitly to conditions in B.C., the broad generalizations inherent in the methodology must be recognized. The emission factors are listed in Appendix C.

To determine N_2O and NO_x emissions from soils, a visual area estimate of the soil orders in each grid square using a soil map of B.C. provided in the Atlas of British Columbia (Farley, 1979) was performed. Then, the emission factors for each encountered soil order were applied, and, taking land areas or water bodies outside the B.C. land mass into account, prorated accordingly. Potential errors introduced by this method were checked by comparing the sum of the land areas within B.C. estimated for each grid square with the total land area of B.C. as estimated in Farley (1979), and further by comparing the results with those given in Environment Canada (1981b). See Appendix

C for details.

2.3.3.2 FOREST FIRES

N_2O emissions were estimated by assigning the N_2O emission factor for wood combustion to the specific SCC for Forest Fires. N_2O emission estimates for this source were then included on the provincial grid. NO_x emission estimates from Forest Fires already exist in the RDIS database.

2.3.3.3 LIGHTNING / OCEANS

N_2O/NO_x emission estimates from Lightning and Marine Waters were obtained from Environment Canada (1981a). The emission factors used for that study appear not to have been superseded by more recent data. These estimates were provided as a gridded summary.

2.4 VOC Emission Sources

2.4.1 *ANTHROPOGENIC SOURCES*

As with anthropogenic NO_x emission sources, it was assumed that anthropogenic VOC emission sources currently compiled in RDIS for the 1985 base year are essentially complete. A recent feature of RDIS allows a plant/process-specific speciation of VOCs into up to 600 different species. Due to computing constraints of the microcomputers available for this project, however, it was not possible to generate gridded VOC speciated summaries for each process for the entire province. With the assistance of Environment Canada staff, however, the speciation program code could be modified to provide VOC speciation summaries on a SIC/grid square basis. By grouping these summaries further into various reactivity classes, the data could provide additional information for further analysis of the NO_x/VOC (as O_3 precursors) emission inventories.

VOC point source emissions data for the Lower Mainland were provided in electronic format by GVRD for integration into RDIS.

VOC emission estimates from all other source categories were generated and gridded using RDIS. A comparison of RDIS VOC source emission estimates for the Lower Mainland and those presented in LOMEI 1985 Summary Report appears in section 3.4. VOC emissions from the Petroleum Refining sector and the Gasoline Marketing sector, which were calculated using RDIS,

were compared with the Canadian Petroleum Products Institute National VOC Emissions Inventory (Levelton/RTM, 1991).

2.4.2 *BIOGENIC SOURCES*

VOC emission estimates were determined for the following biogenic emission sources:

- Vegetation
- Forest Fires

Hydrocarbon emissions from other natural sources such as soils, animals, marine and fresh water environments are primarily alkanes (methane predominating), and therefore are not considered in this study (Environment Canada, 1985).

2.4.2.1 VEGETATION

Vegetation is by far the largest source of biogenic VOC emissions. Emission data for B.C. were obtained from Environment Canada (1989b). Canopy VOC emissions were determined in the Environment Canada study using an eight layer canopy model and were corrected in the same study for B.C. using hourly temperature, wind, humidity and cloud data from three climate zones. These data were subsequently redistributed for the Greenhouse Gases Inventory, based on the corresponding climate zones, among each of the grid squares in RDIS.

In the 1989 Environment Canada study, VOC emissions from vegetation were speciated into the following classes:

- isoprene
- alpha-pinene
- other Mono-terpenes
- others

The first three of these classes play an important role in atmospheric chemistry, including ozone production. Emissions of VOCs from Vegetation assigned to the Lower Mainland grid square in RDIS were compared with natural VOC estimates in the LOMEI 1985 Area Sources Summary Report (see section 3.4).

2.4.2.2 FOREST FIRES

As mentioned above, emission estimates from Forest Fires, including VOCs, already exist in the RDIS database. Emissions of VOCs from Forest Fires assigned by RDIS to the Lower Mainland grid square were also compared with VOC estimates in the LOMEI 1985 Area Sources Summary Report (see section 3.4).

2.5 Other Anthropogenic Sources

Anthropogenic NO_x, VOC and N_2O emissions from two additional sources, neither of which were included in RDIS or LOMEI for the 1985 base year, were added to this inventory. The first, B.C. Hydro's Burrard Thermal Generating Plant located in the Lower Mainland, was considered as a Fuel Combustion source. The second, GVRD's Burnaby MSW Incinerator, which is also located in the Lower Mainland, was considered as an Incineration source. Being part of the updated version of the 1985 LOMEI compiled for stage one of the GVRD Air Management Plan (Concord, Levelton 1989b), these two sources were incorporated into the Greenhouse Gases Inventory.

N_2O emissions from Burrard Thermal were estimated using the N_2O emission factor for natural gas combustion, while N_2O emissions from the Burnaby incinerator were estimated using the N_2O emission factor for wood as a surrogate for cellulosic materials. NO_x and VOC emissions and fuel rates were provided by plant personnel (B.C. Hydro, 1991b; GVRD, 1991) and from Concord/Levelton (1989b). A summary of emissions from each of these facilities follows:

	Emissions (annual tonnes)		
Source	NOx	N_2O	VOC
Burrard Thermal Generating Plant	2200	0.45	24
Burnaby Incinerator	312	25	61

2.6 Ozone (O_3) Inventory

The inventory of ozone has been approached in terms of its precursor emissions - that is, of NO_x and VOCs. Algorithms were found in the literature which permit the emission inventory of NO_x and VOCs to be used to estimate total ozone production from these emissions. Ozone production

from biogenic and anthropogenic precursors on a regional scale such as is appropriate for B.C. can be estimated using a photochemical box model. A photochemical box model of continental and global atmospheric chemistry developed by Liu et al. (1987) allows the establishment of a simple relationship between ozone production, nitrogen oxides emissions and the lifetime of nitrogen oxides in the atmosphere. Liu et al (1987) have shown that within a region which can be considered large enough to contain most of the important sources of NO_x and VOCs, the production of ozone can be related to the NO_x emissions by the following relationship:

$$S = E \cdot \tau \cdot \Delta P$$

where S is the total O_3 produced due to the NO_x emissions E in the region, denotes the NO_x lifetime, and ΔP is the daily O_3 production per ppb_v of NO_x. The product $\tau \cdot \Delta P$ is the number of ozone molecules produced per molecule of NO_x emitted. This ratio is also essentially the ratio of mass of ozone produced per mass of NO_x emitted (accurate enough for the purpose of this analysis). Data are available to estimate the required parameters for the B.C. grid. The ratio of ozone produced to NO_x emitted varies with the background concentration of NO_x, being greater for lower concentrations of NO_x.

The model includes an extensive set of chemical reactions which include biogenic and anthropogenic hydrocarbon emissions. For a more detailed description of the model, see Liu et al. (1987). The results of using this approach are shown in Section 3.5.

The ozone production potential of NO_x and VOCs has also been accounted for by using a global relationship which has been proposed by the Intergovernmental Panel on Climate Change (IPCC) in their report on the scientific basis of current information on global warming (IPCC, 1990). Contributors to the IPCC report have determined the Global Warming Potentials of a number of greenhouse gases relative to carbon dioxide. These Global Warming Potentials allow estimates of the equivalent amount of carbon dioxide which corresponds to the effect of the ozone produced from a given amount of ozone precursor emissions (i.e., NO_x and VOC). For more details of this approach, see IPCC (1990), Chapter 2, especially Section 2.2.7. This approach permits direct estimates to be made of the equivalent quantity of CO_2 corresponding to a given quantity of ozone precursor emissions. Therefore, the latter method has been used to estimate the ozone production from the NO_x and VOC precursor emissions (see Section 3.1). The method of Liu et al has been used to check the results of the IPCC approach, as shown in Section 3.5.

3.0 RESULTS AND ANALYSIS

Throughout this report, data are presented using more than the justifiable significant figures. Excess significant figures are carried, not to imply greater precision, but for reasons of consistent data presentation. Generally, data reported in this study will not be precise to more than 2 significant figures. An analysis of data uncertainties follows in section 3.7.

The amount of data gathering, manipulation and integration required to compile a provincial $NO_x/VOC/O_3$ inventory within RDIS created a potential risk for data corruption. As an initial check of the validity of the $NO_x/VOC/O_3$ inventory, the following comparisons with other inventories were made:

Parameter	$NO_x/VOC/O_3$ Inventory (tonnes)	NO_x/VOC Mgmt Plan[2] (tonnes)	B.C. Point Source Inventory[3] (tonnes)
Total Anthropogenic (NOx)	264910	252600	
Total Anthropogenic (VOC)	284580	294400	
Total Industrial Sources (NOx)[1]	47550	10700	47181
Total Industrial Sources (VOC)[1]	58880	14700	55632
Transportation (NOx)	193590	185400	
Transportation (VOC)	127990	113800	
Fuel Combustion (NOx)	12190	45200	
Fuel Combustion (VOC)	4500	47100	
Incineration/Miscellaneous (NOx)	11580	11300	
Incineration/Miscellaneous (VOC)	89780	118800	

1. Including LOMEI Point Sources
2. CCME, 1990
3. BC MOE, 1989

In general, emission summaries among the various inventories compare favourably. The apparent discrepancies in the Industrial Processes and Fuel Combustion sources appear to be the result of differing methods in assigning source sectors. There are more significant detailed discrepancies

within each of the above sectors, however, the reasons for this are beyond the scope of this study, and they do not appear to affect the totals for the sectors appreciably.

Data compiled were not compared with the updated, preliminary version of the National Emissions Inventory (1990), which was prepared to support the NO_x/VOC Management Plan, as those data have been revised from the 1985 base year data in RDIS. Revisions pertinent to B.C. were provided to the study team during the project period.

3.1 Summary of NO_x, N_2O and VOC Emissions

A summary of NO_x, N_2O and VOC emissions compiled for British Columbia is presented in Tables 2 and 3. A detailed categorization of major anthropogenic emissions by source sector (Standard Industrial Code) and by process (Source Classification Code) is presented in Appendix D. A detailed categorization of source sectors, as defined in RDIS, is provided in Appendix B.

Provincial total emissions for NO_x, N_2O and VOC have also been expressed in terms of "CO_2 equivalents" in Figures 2 and 3 and Table 3. This approach is based on the concept of Global Warming Potentials which was developed in the IPCC Scientific Assessment (IPCC, 1990). The definition of the Global Warming Potential is given by the following equation. Qualitatively, the GWP is the time-integrated contribution to climate forcing from the instantaneous release of 1 kg of a greenhouse gas expressed relative to that from 1 kg of CO_2.

$$GWP = \int a_i \, c_i \, dt \, / \int a_{CO2} \, c_{CO2} \, dt,$$

where a_i is the instantaneous radiative forcing of the gas due to a unit increase in the concentration of the gas, c_i is the concentration of the gas remaining at time t after its release, and the integration is carried out over a period of years, zero to n. The corresponding quantities for carbon dioxide are in the denominator. Some of the important properties are given in the table in the Introduction.

The appropriate time period over which to integrate the GWP is somewhat arbitrary, but the period selected for this analysis is 100 years. The relative contributions of the various greenhouse gases vary with the time period considered. This period was chosen so that the results could be compared directly with other data provided in the IPCC report (IPCC, 1990), and this period also makes sense in the context of the long-term perspective of the results of management of greenhouse gases. The concept of the GWP is new, and this approach is currently being refined and the reliability of the values improved.

The Global Warming Potential of a greenhouse gas can be used to relate its impact to an equivalent amount of CO_2. The GWPs for NO_x, N_2O and VOC were obtained from IPCC (1990), as amended by Johnson et al. (C. Johnson and R. Derwent, private communications, 1991) and are shown in the tables below. The GWPs for NO_x and VOC are based on their acting as precursors of ozone formation. VOCs also make a greenhouse gas contribution directly to CO_2, since their fate in the atmosphere is to be oxidized to CO_2. The GWPs shown in the tables indicate both of these contributions. N_2O is a direct-acting greenhouse gas itself.

Trace Gas	**Estimated Lifetime** (years)	**Global Warming Potential** (per unit mass emitted and assuming a 100-year integration time)
CO_2	~120	**1**
N_2O	150	**290**

Source Gas (Indirect Effects)	**Greenhouse Gas Affected**	**Global Warming Potential** (assuming 100-year integration time)
NO_x	Tropospheric Ozone	**7**
VOC (as NMHC)[1]	Tropospheric Ozone	**8**
VOC (as NMHC)[1]	CO_2	**3**

1. NMHC - non-methane hydrocarbons

Table 2. SUMMARY of NOx / VOC EMISSIONS for British Columbia (1985)

SOURCE	NO_x (tonnes)	N_2O (tonnes)	VOC (tonnes)
Anthropogenic			
1. B.C. Total	264910	7880	284580
2. B.C. Total Industrial Processes [1]	47550	950	58880
B.C. Industrial Processes[2]	38830	805	51150
B.C. Fuel Combustion [3]	12190	125	4500
B.C. Transportation	193590	3020	127990
B.C. Incineration [4]	2550	430	2380
B.C. Miscellaneous	9030	490	87400
B.C. Open Sources [5]	0	0	3430
3. B.C. Industrial Processes	38830	805	51150
Cement & Concrete Manufacturing	50	0.1	0
Forestry	18780	770	43400
Mining	1410	2	2.5
Oil & Gas Production	10170	7	1630
Other Industrial Fuel Combustion	1400	20	740
Other Industries	3180	3	630
Petrochemical	452	0.7	1340
Primary Metals	2390	1.6	20
Petroleum Refining	1000	0.7	3670

Table 2 (Cont'd). SUMMARY of NOx / VOC EMISSIONS for British Columbia (1985)

SOURCE	NO_x (tonnes)	N_2O (tonnes)	VOC (tonnes)
4. Included in B.C. Fuel Combustion			
B.C. Hydro Thermal Generating Plant	2200	0.5	24
5. Included in B.C. Incineration			
Burnaby Incinerator	310	25	60
6. LOMEI Industrial Point Sources	8720	140	7730
Cement & Concrete Manufacture	4290	na	70
Chemical	270	na	210
Forestry	1220	na	1170
Other Industries	850	na	850
Petroleum Refining	2090	na	5430
7. Fertilizer Application	0	330	0
8. Anaesthetics	0	140	0
9. Aerosols	0	7.5	0
10. Transmission Lines [6]	negligible	2390	0

Notes

1. Includes #3 and #6.
2. Includes only #3.
3. Includes #4.
4. Includes #5.
5. Excludes forest fires which are considered to be a biogenic source.
6. Major Transmission Lines are estimated to produce 300-800 tonnes O_3 and less than 100 tonnes NO_x. na. not available

Table 2 (Cont'd). SUMMARY of NOx / VOC EMISSIONS for British Columbia (1985)

SOURCE	NO_x (tonnes)	N_2O (tonnes)	VOC (tonnes)
Biogenic			
1. B.C. Total Biogenic	50725	40750	2572300
2. B.C. Vegetation	0	0	2509670
Speciated: isoprene 279920; alpha-pinene 659470; monoterpenes 647460; others 922820			
3. Soils	35800	35160	0
4. Forest Fires	11510	520	62600
5. Marine Waters	0	5020	0
6. Lightning	3410	57	0

The inventory data in Table 2 may be converted to "CO_2 equivalents" straightforwardly by multiplying the actual inventory quantities by the Global Warming Potentials in the tables above. This has been done in Table 3. The data expressed in this form allow the relative impact of the gases of this inventory to be compared directly with CO_2, and with other greenhouse gases. This common base of expressing the global warming potential of the emissions also provides a rational basis for assessing management measures.

The results labelled $NO_x(O_3)$ and $VOC(O_3)$ in Table 3 together are essentially the ozone inventory for B.C. expressed in terms of equivalent quantities of CO_2. Estimates of the actual quantity of ozone to which these results correspond are derived in Section 3.5.

Although it is recognized that the global warming potentials used for indirect effects are highly model dependent and require further revision and evaluation, they nevertheless permit an initial assessment of global warming impact potentials from emission sources in British Columbia. For example, the global warming potential for NMHCs (VOCs) is derived from a global average ozone productivity. The actual productivity depends upon climatic factors (primarily temperature and sunlight) and the reactivity of accompanying hydrocarbon species.These global warming potentials allow an approximate approach to estimating impacts from ozone production, which can then be compared with estimates made using B.C.-specific data.

As CO_2 equivalents, biogenic sources are estimated to account for 85% of the total $NO_x/N_2O/VOC$ emissions in B.C., while Transportation emits 7.6%, and the sources Industrial Processes/LOMEI Point Sources/Fuel Combustion, 3% of the total (Figures 2 and 3).

A CO_2 equivalents emission breakout has been provided for the Transportation sector, which is estimated to be the largest anthropogenic contributor to the Greenhouse Gases Inventory for B.C. (Figures 4 and 5). As CO_2 equivalents, this sector is estimated to account for 50% of anthropogenic $NO_x/N_2O/VOC$ emissions. Other fossil fuel combustion sources, as defined in Industrial Processes, LOMEI Point sources and Fuel Combustion sources, are estimated to account for 19.6% of total anthropogenic $NO_x/N_2O/VOC$ emissions, while Miscellaneous sources (i.e. Slash Burning, Fuel Marketing, Solvent Use, Surface Coatings, etc.) are estimated to account for 16%. N_2O emissions from Transmission Lines may contribute as much as 1.5% of the total anthropogenic and biogenic emissions of $NO_x/N_2O/VOC$ in the province (Figure 2).

Table 3. SUMMARY of NOx / VOC EMISSIONS as CO2 equivalents for British Columbia (1985)

SOURCE	$NO_x(O_3)$[a] (kt)	N_2O (kt)	VOC (O_3)[b] (kt)	VOC (CO_2)[c] (kt)	Total (kt)
Anthropogenic					
1. B.C. Total	1854	2285	2276	854	7270
2. B.C. Total Industrial Processes [1]	333	276	471	177	1257
B.C. Industrial Processes	272	232	409	153	1066
B.C. Fuel Combustion	85	36	36	14	171
B.C. Transportation	1355	876	1024	384	3639
B.C. Incineration	18	125	19	7	169
B.C. Miscellaneous	63	142	699	262	1166
B.C. Open Sources [2]	0	0	27	10	37
3. LOMEI Industrial Point Sources	61	41	62	23	187
4. Fertilizer Application	0	96	0	0	96
5. Anaesthetics + Aerosols	0	43	0	0	43
6. Transmission Lines [3]	3	693	0	0	693

Notes

1 Includes BC Industrial Processes and LOMEI Industrial Point sources

2 Excludes forest fires which are considered to be a biogenic source

3 Major Transmission Lines are estimated to contribute minor amounts of ozone and NO_x (1-3 kT CO_2 equiv.) in addition to N_2O

a CO_2 equivalent of ozone produced from NO_x through atmospheric photochemistry

b CO_2 equivalent of ozone produced from VOC/NMHC through atmospheric photochemistry

c CO_2 produced from VOC/NMHC by atmospheric oxidation

Table 3 (Cont'd). SUMMARY of NOx / VOC EMISSIONS as CO2 equivalents for British Columbia (1985)

SOURCE	$NO_x(O_3)$[a] (kt)	N_2O (kt)	VOC (O_3)[b] (kt)	VOC (CO_2)[c] (kt)	Total (kt)
Biogenic					
1. B.C. Total Biogenic	355	11818	20578	7717	40468
2. B.C. Vegetation	0	0	20077	7529	27606
3. Soils	250	10196	0	0	10446
4. Forest Fires	81	151	500	189	921
5. Marine Waters	0	1456	0	0	1456
6. Lightning	24	17	0	0	41

Notes

a CO_2 equivalent of ozone produced from NO_x through atmospheric photochemistry

b CO_2 equivalent of ozone produced from VOC/NMHC through atmospheric photochemistry

c CO_2 produced from VOC/NMHC by atmospheric oxidation

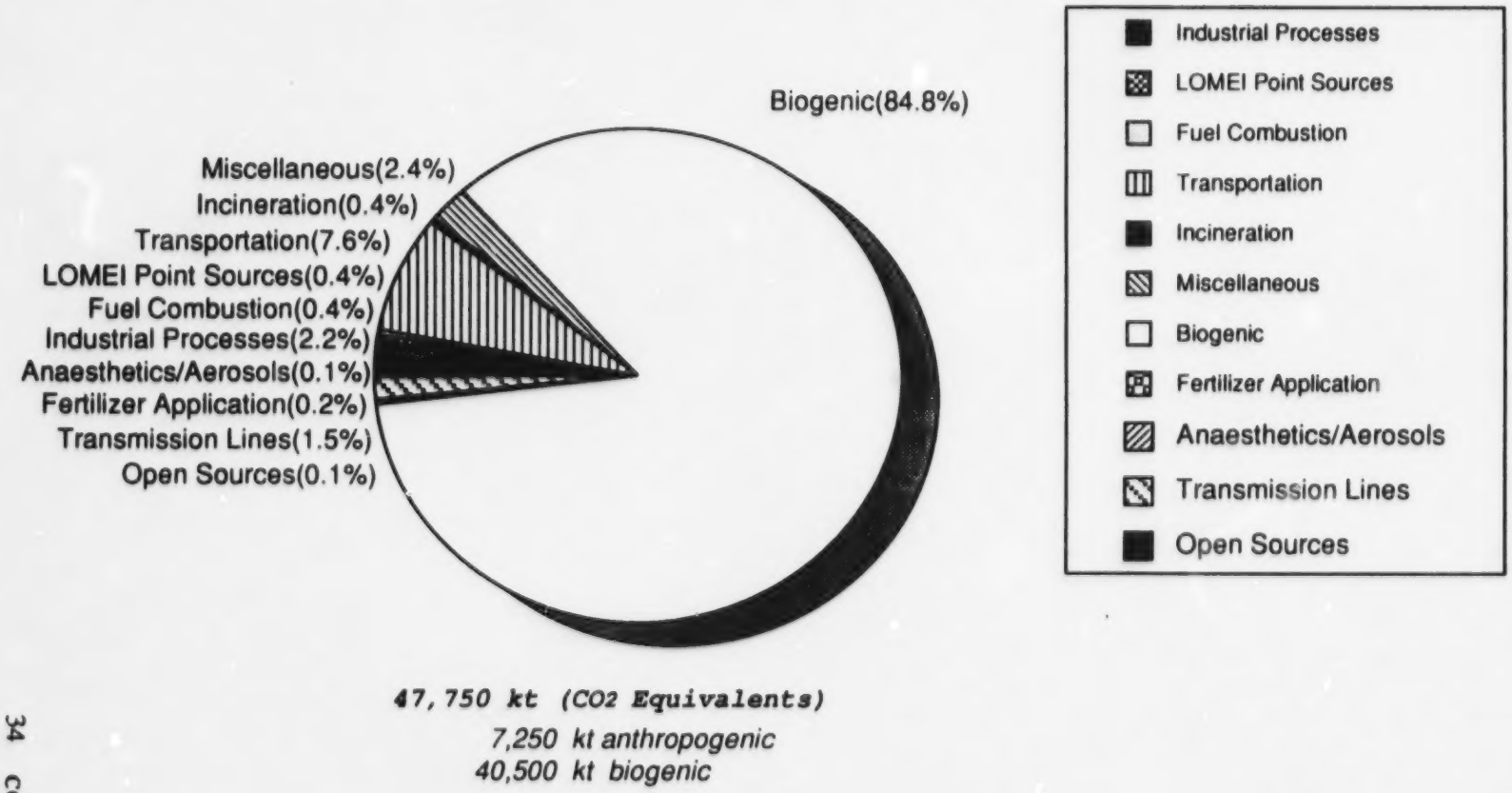


FIGURE 2. Total NOx/N2O/VOC Emissions By Sector as CO2 Equivalents (1985)

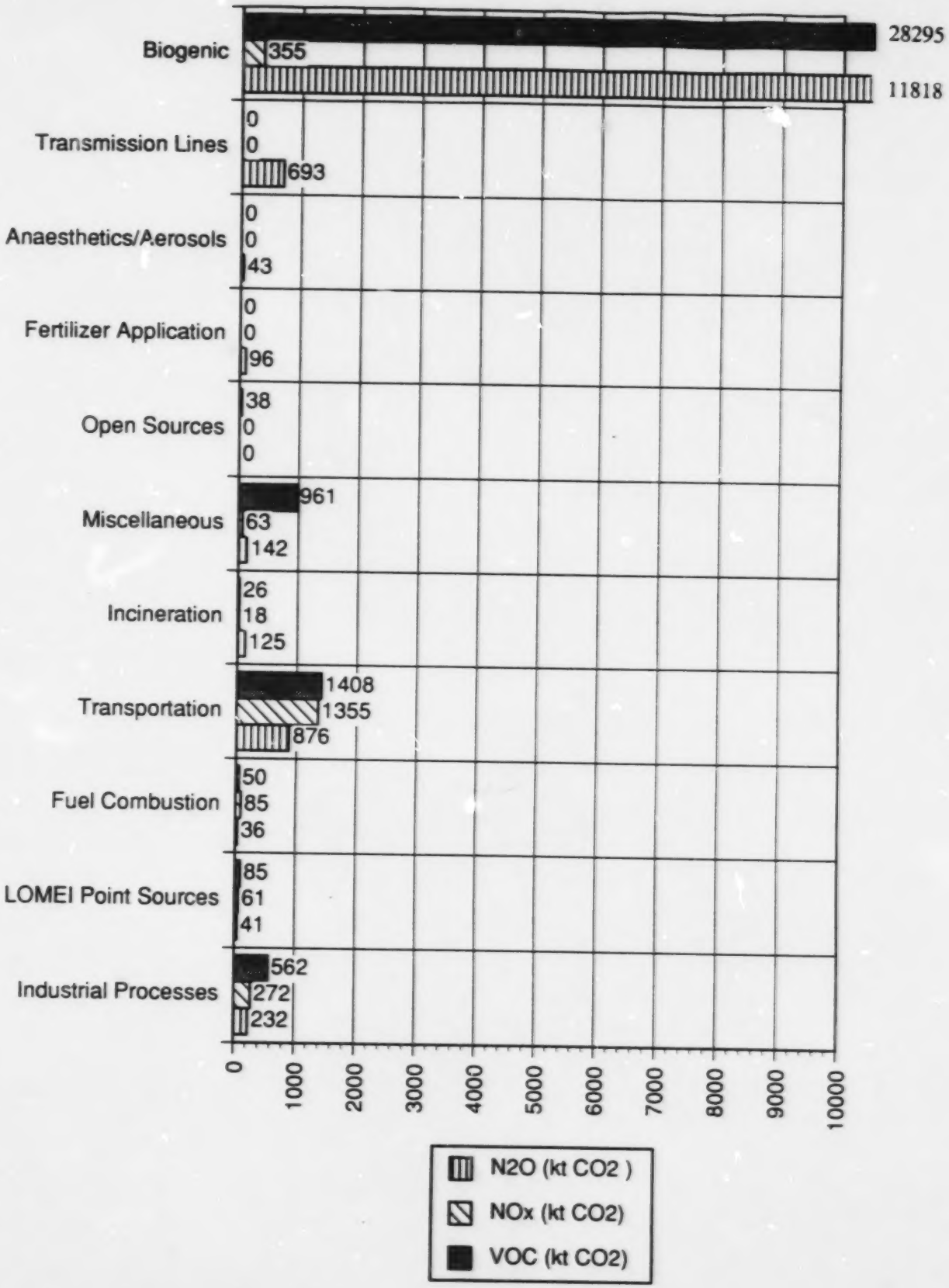


FIGURE 3. Total NOx/N2O/VOC Emissions as CO2 Equivalents (kilotonnes) (1985)

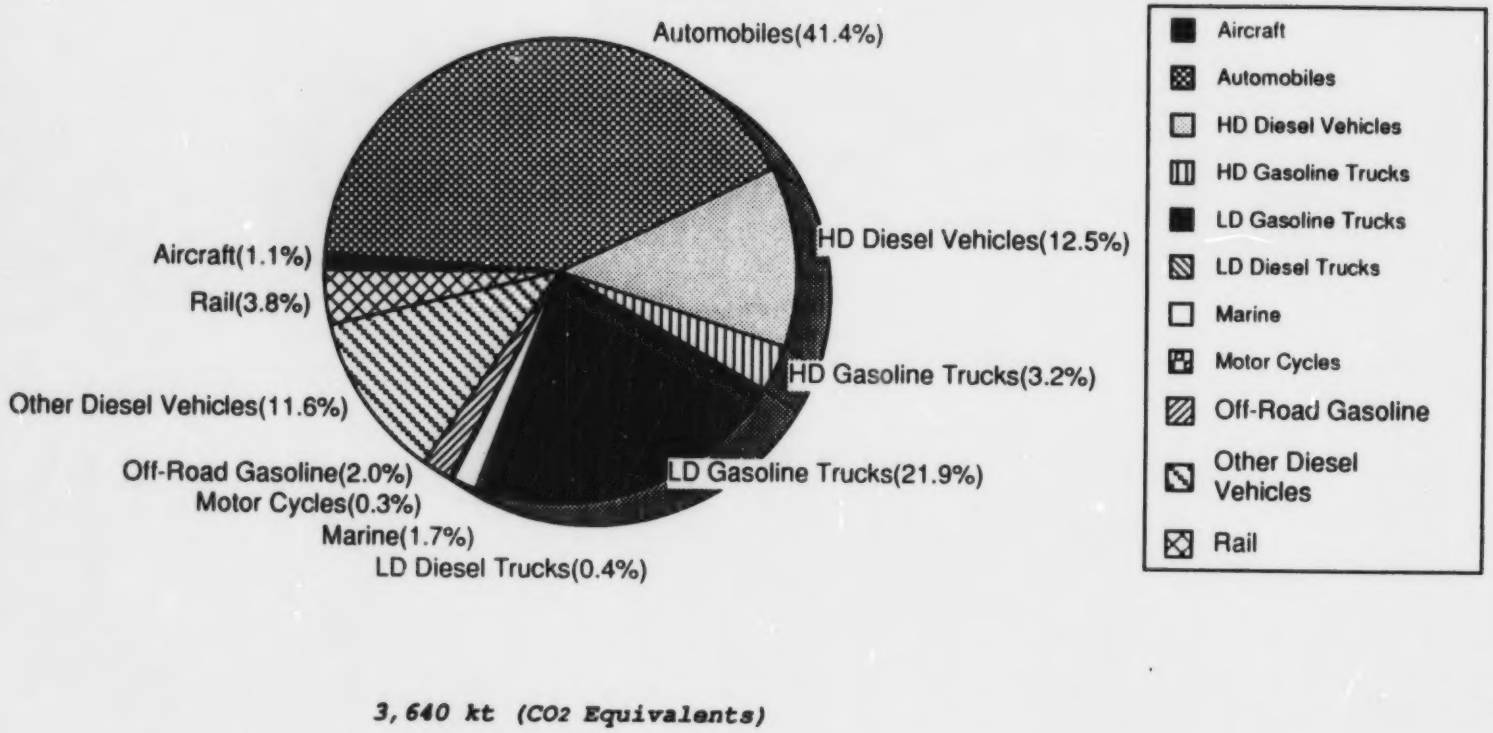


FIGURE 4. Transportation NOx/N2O/VOC Emissions By Sector as CO2 Equivalents (1985)

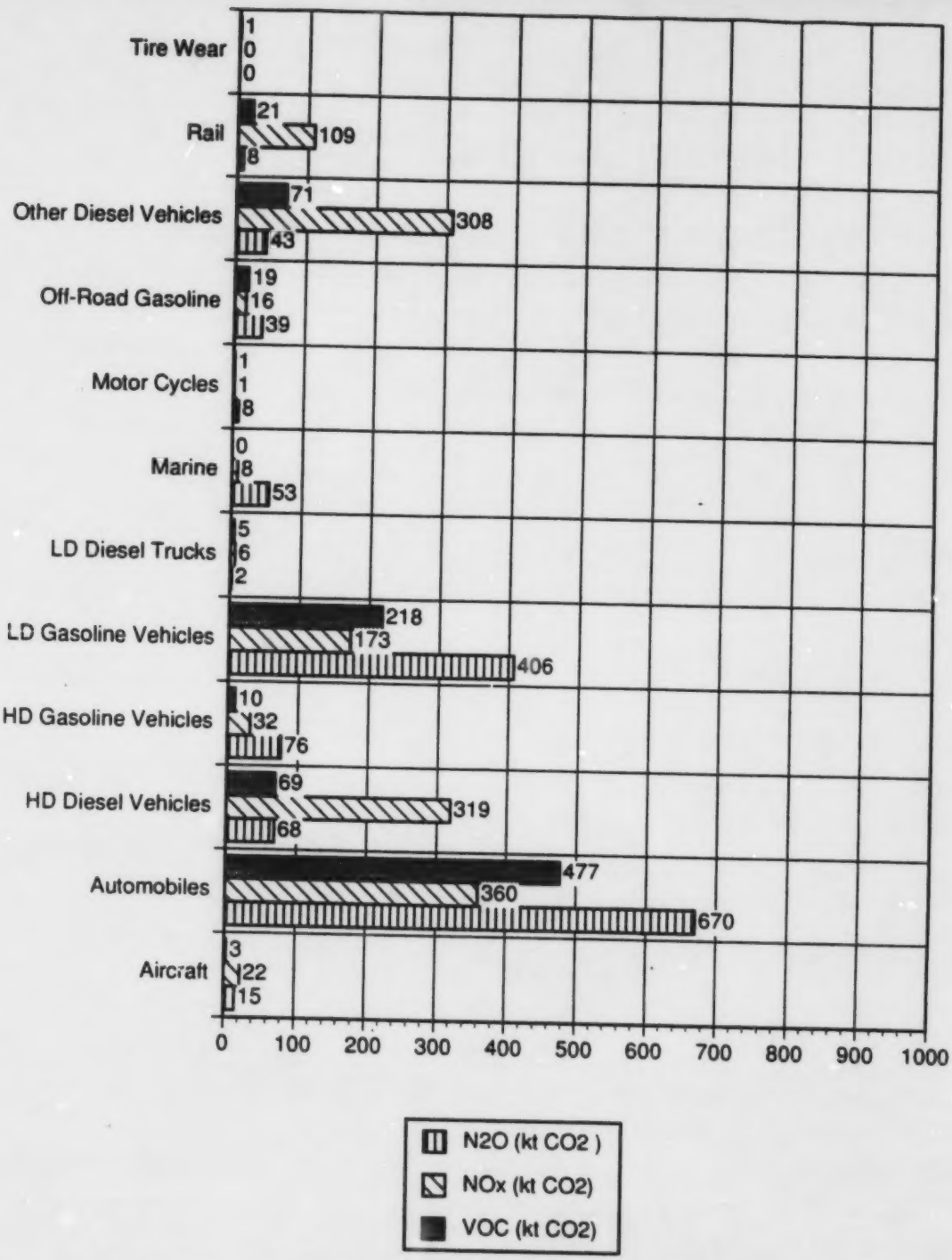


FIGURE 5. Transportation NOx/N2O/VOC Emissions as CO2 Equivalents (kilotonnes) (1985)

3.2 Detailed NO_x and VOC Emissions by Sector

The total amount of anthropogenic and biogenic NO_x emitted in British Columbia in 1985 is estimated to be 315,640 tonnes (Figures 6 and 7). Of this, the largest contributor is the Transportation sector, emitting 61% of the total, followed by Biogenic sources which emit 16%, Industrial /LOMEI point sources which account for 15%, and Fuel Combustion sources which account for 4% of the total NO_x emissions, respectively.

The total amount of anthropogenic and biogenic VOCs emitted in B.C. is estimated to be 2,860,000 tonnes (Figures 8 and 9). It is estimated that up to 90% of these emissions occur naturally while the sectors Transportation, Miscellaneous and Industrial Processes / LOMEI Point sources contribute 4.5%, 3% and 2%, respectively.

3.2.1 *TRANSPORTATION*

Road vehicles collectively account for the majority (89%) of NO_x emissions and 90% of the VOC emissions in the Transportation sector (Figure 10). While the Transportation sector is estimated to emit 73% of the anthropogenic NO_x and 45% of total anthropogenic VOC, road vehicles account for 65% of total anthropogenic NO_x and 40% of total anthropogenic VOC emitted in the province.

3.2.2 *BIOGENIC*

Soil nitrification and denitrification processes are estimated to account for 70% of all biogenic NO_x emissions, while Forest Fires and Lightning are estimated to emit 23% and 7%, respectively. VOCs from Vegetation are estimated to produce more than 99% of the biogenic emissions in the province. Forest Fires are considered to be the only other significant contributor to biogenic VOCs. Figure 11 shows these emissions speciated into four compound groups. Other natural sources such as soils, aquatic environments and enteric fermentation are thought to emit predominantly methane, and are, therefore, not included in this inventory.

3.2.3 *INDUSTRIAL PROCESSES /LOMEI POINT SOURCES*

The forestry sector in B.C. accounts for 42% of the NO_x emissions in the Total Industrial Processes sector (Figures 12 and 13) and contributes 7.5 % of the total anthropogenic NO_x. For

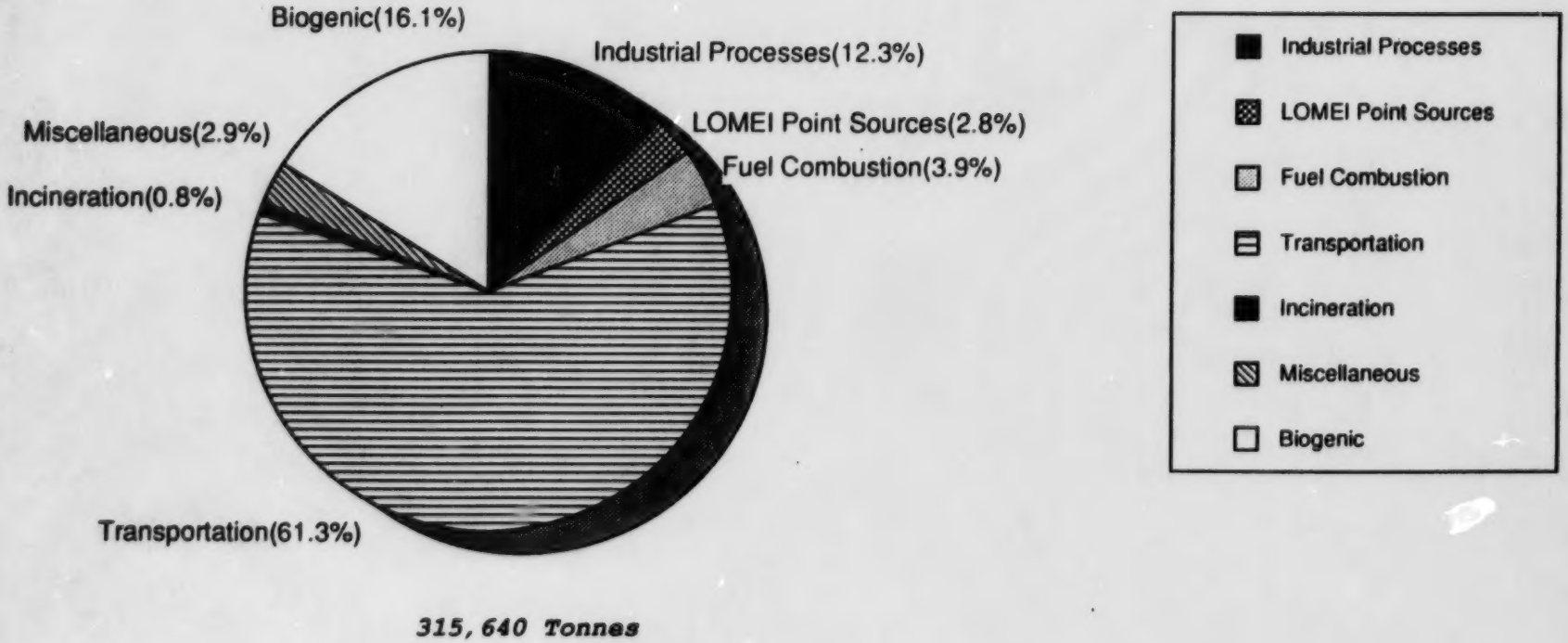


FIGURE 6. Total NOx (NO, NO2) Emissions By Sector (1985)

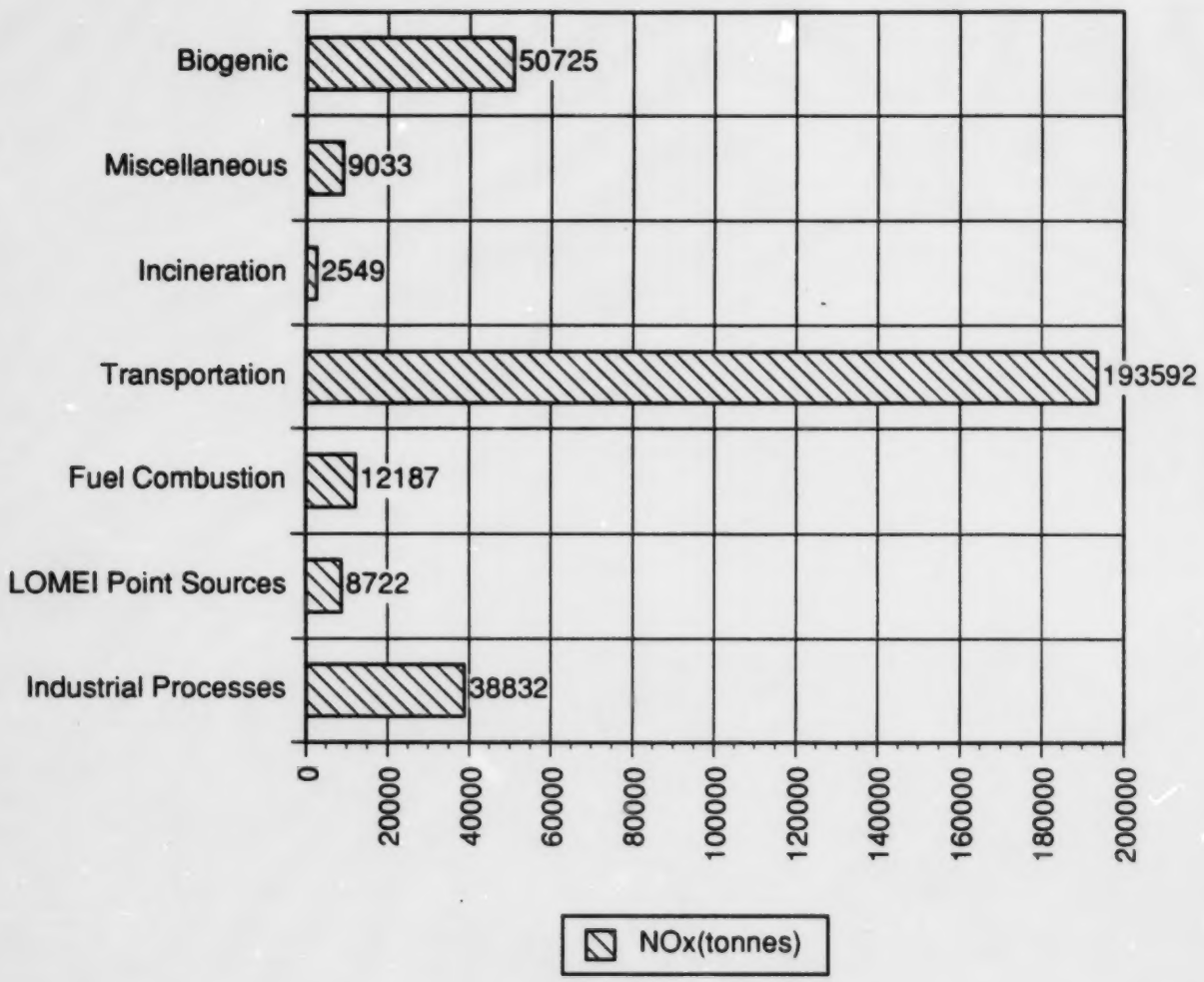
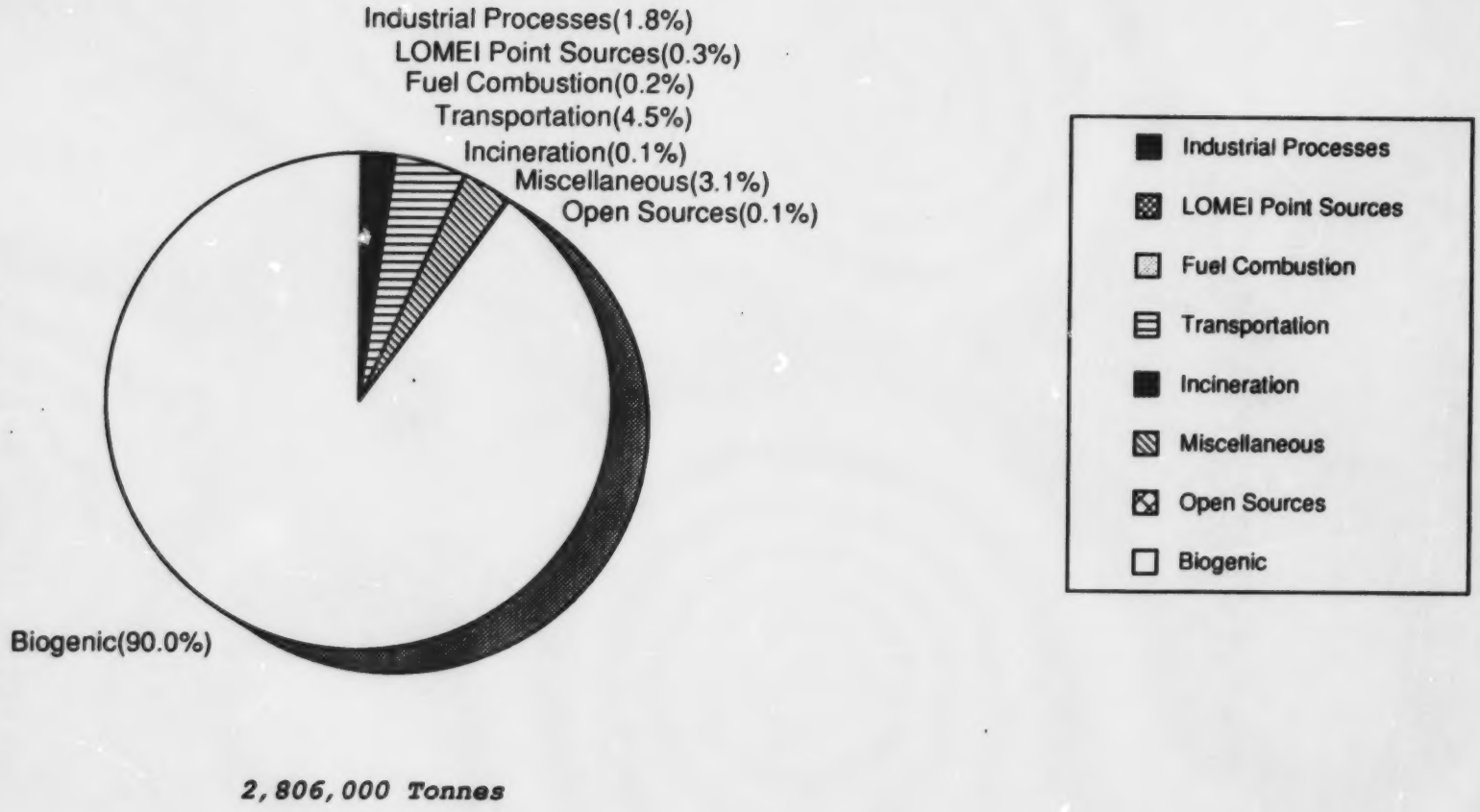


FIGURE 7. Total NOx Emissions By Sector (1985)



2,806,000 Tonnes

FIGURE 8. Total VOC Emissions By Sector (1985)

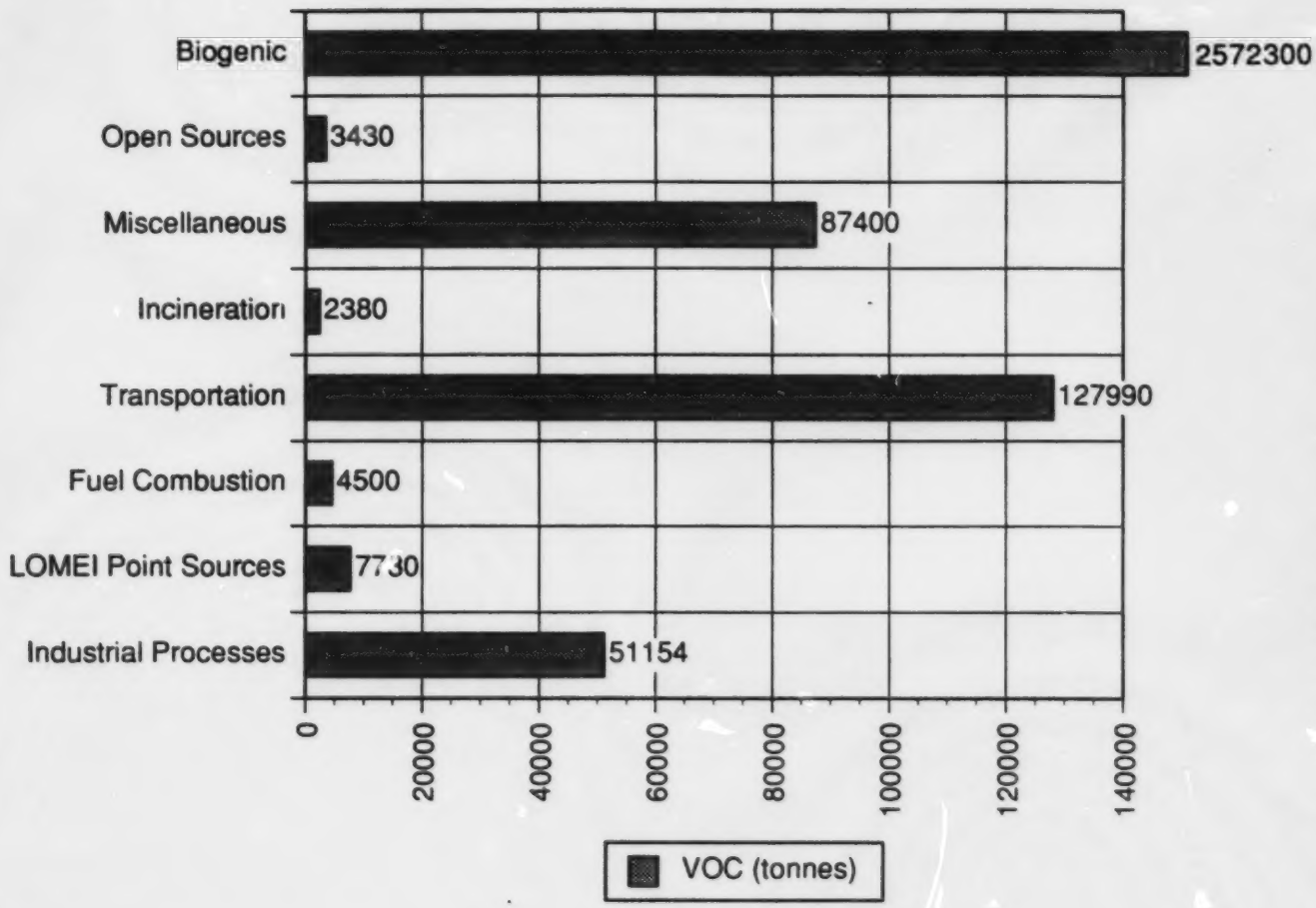


FIGURE 9. Total VOC Emissions By Sector (1985)

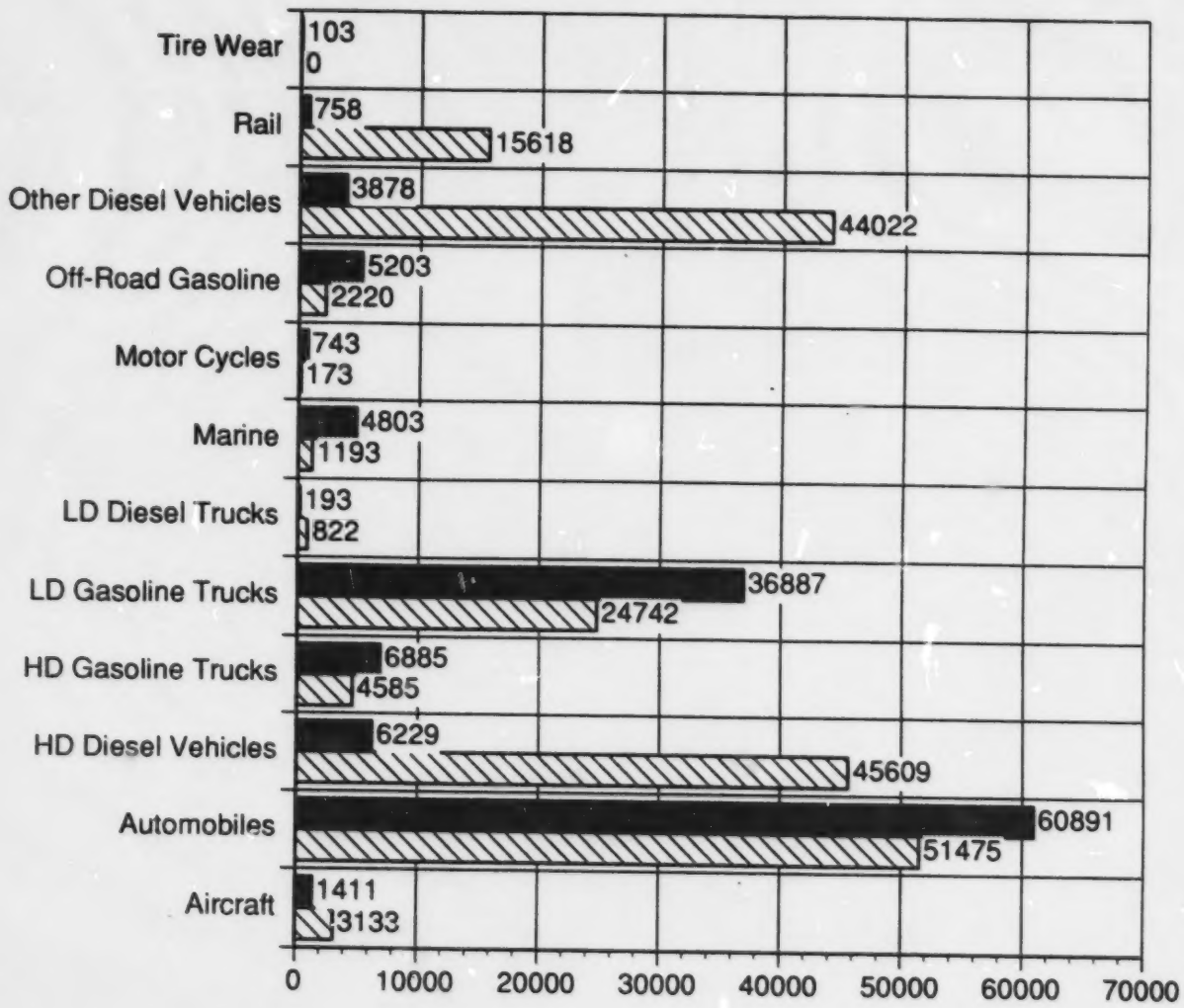


FIGURE 10. NOx/VOC Emissions By Major Transportation Sector (1985)

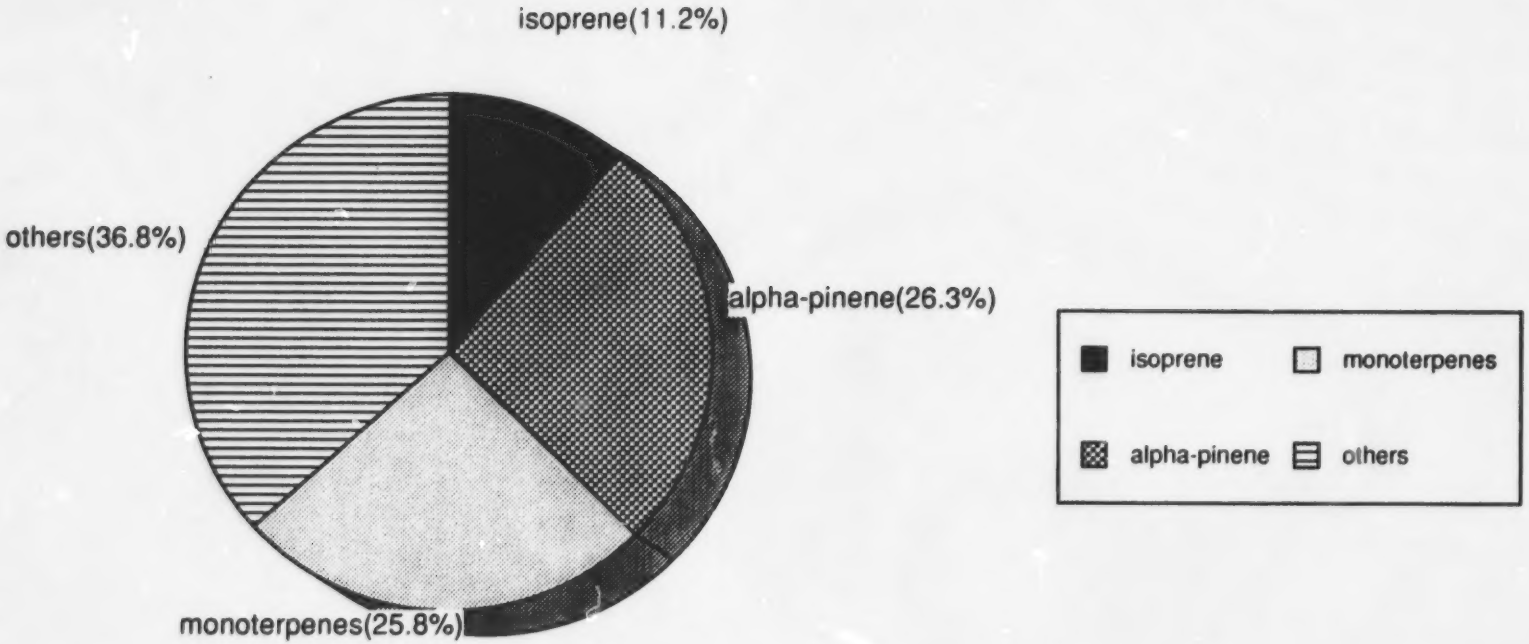


FIGURE 11. VOC Speciation of Biogenic Emissions From Vegetation (1985)

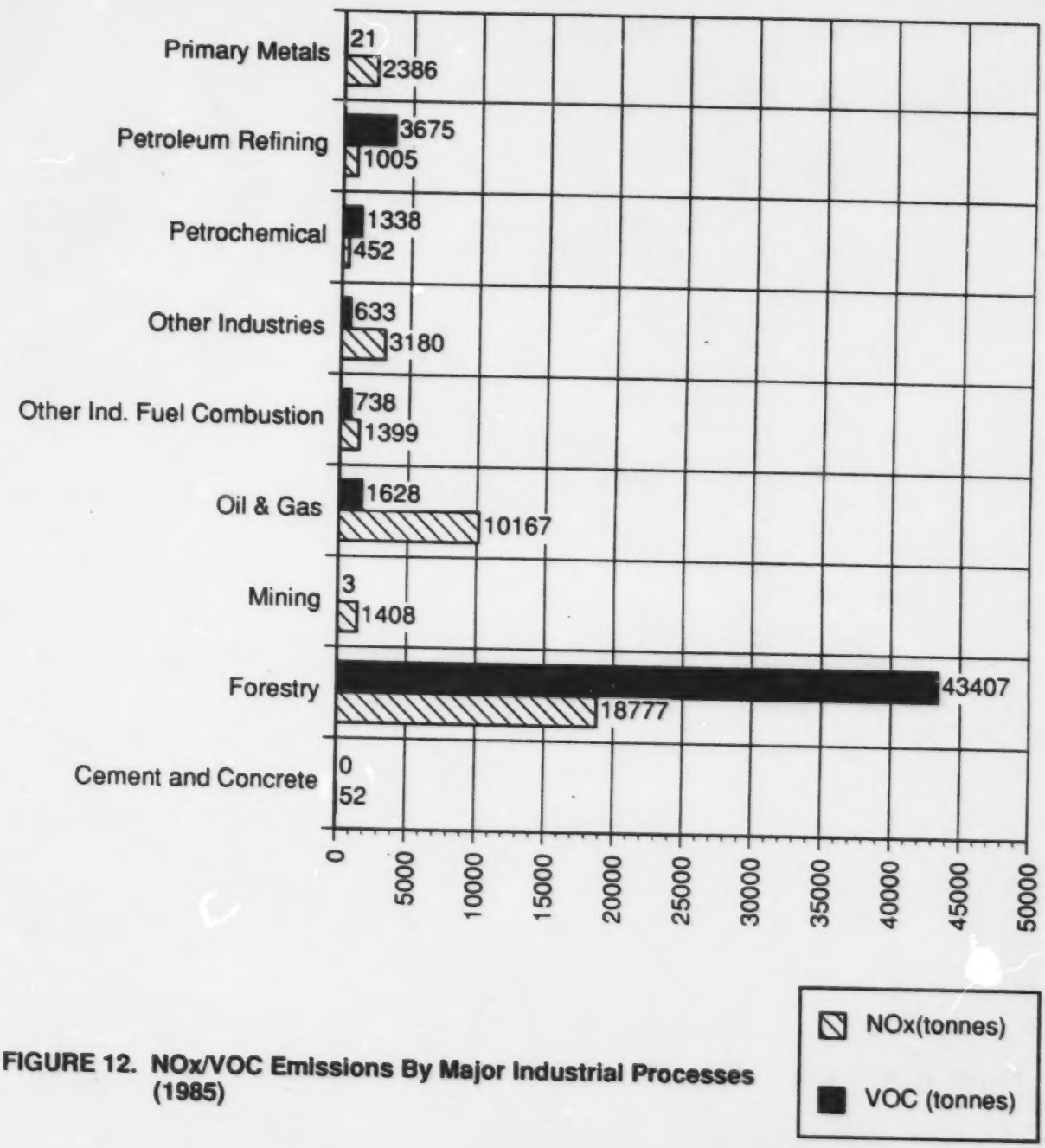


FIGURE 12. NOx/VOC Emissions By Major Industrial Processes (1985)

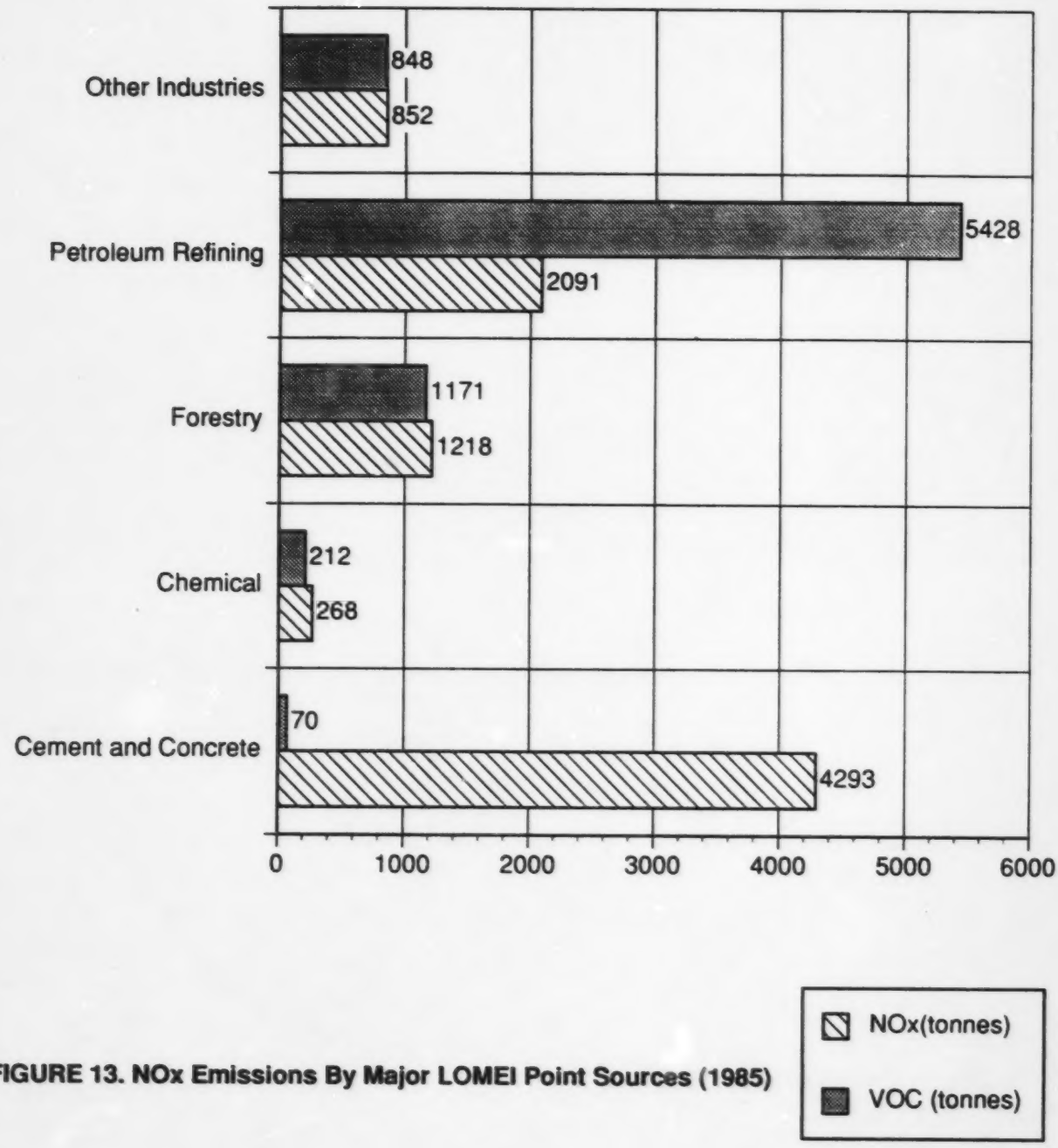


FIGURE 13. NOx Emissions By Major LOMEI Point Sources (1985)

VOCs the contribution is 75% in the Total Industrial Process sector, which is 15 % of the total anthropogenic VOC. Oil & Gas, Cement & Concrete, Other Industries and Petroleum Refining are estimated to contribute 21%, 9%, 8%, and 6.5% of NOx emissions in the Total Industrial Processes sector, respectively. Petroleum Refining, Oil & Gas, and Other Industries, are estimated to contribute 15%, 3%, and 3% of VOC emissions in this sector, respectively. It was assumed for this study that the Other Industrial Fuel Combustion sector within the Lower Mainland, as defined in RDIS, was accounted for within the point source sectors defined in LOMEI.

3.2.4 *FUEL COMBUSTION*

Power Generation, as defined in RDIS, is estimated to account for 48% of the NO_x emissions in the Fuel Combustion sector. The Fuel Combustion sector contributes 4.6% of the total anthropogenic NO_x emissions. B.C. Hydro's Burrard Thermal Generating Plant is estimated to account for 18% of the NO_x emission in the Fuel Combustion sector, while the remaining Power Generation NO_x emissions are due mainly to diesel-fired generators. Residential Combustion and Commercial Combustion account for 28% and 22% of the total NO_x emissions from this sector.

It is estimated that Residential Fuelwood Combustion accounts for 85% of VOC emissions from Fuel Combustion sources. VOC emissions from the Fuel Combustion sector are approximately 1.5% of total anthropogenic VOC emissions.

3.2.5 *MISCELLANEOUS*

Slash Burning is estimated to account for 100% of NO_x emissions in the Miscellaneous sector and 50% of VOC emissions and thereby contributes about 3% of the total anthropogenic NO_x and 15% of total anthropogenic VOC. Application of Surface Coatings accounts for 16% of VOC emissions in the sector Miscellaneous, while Fuel Marketing, Solvent Use, and Dry Cleaning account for 14%, 14%, and 6% of VOC emissions, respectively.

3.2.6 *OTHERS*

It is estimated that Wood Waste Incineration (in wigwam burners) accounts for 82% of the NO_x emissions and 96% of the VOC emissions from Incineration sources in B.C. By comparison, GVRD's Burnaby Incinerator is estimated to emit 12% of the total Incineration NO_x emissions and 2.5% of the total Incineration VOC emissions. NO_x and VOC emissions in the Incineration sector

each account for approximately 1% of total anthropogenic emissions. Given the close relationship which exists between Wood Waste Incineration (wigwam burners) and much of Slash Burning with the Forestry sector, these two categories need to be taken into account in assessing this sector's contribution to overall anthropogenic emissions.

3.3 Detailed N_2O Emissions by Sector

The total amount of anthropogenic and biogenic N_2O emitted in British Columbia in 1985 is estimated to be 48,630 tonnes (Figures 14 and 15). Of this, the largest contributors are biogenic sources, emitting 84% of the total, followed by Transportation sources which emit 6% of the total. and Transmission Lines which account for 5% of the total N_2O emissions.

3.3.1 *BIOGENIC*

As with biogenic NO_x emissions discussed above, Soil Nitrification and Denitrification processes are the dominant biogenic sources of N_2O emissions in B.C., accounting for 86% of the provincial biogenic total. Marine Waters are also significant biogenic emitters of N_2O with 12% of the biogenic total, while Forest Fires and Lightning account for 1% and 0.1%, respectively.

3.3.2 *TRANSPORTATION*

Transportation sources are estimated to account for 38% of total anthropogenic N_2O emissions or 6% of the overall N_2O emissions in B.C. (Figures 14 and 15). The breakdown of N_2O emissions in the Transportation sector is similar to that for NO_x emissions, as discussed above, in that road vehicles are the dominant source of emissions in this sector (Figure 16). N_2O emission estimates for Off-road Use of Gasoline and Marine sources were not possible due to insufficient data. Neither RDIS nor LOMEI accounts for natural gas- or LPG-powered vehicles in the 1985 inventories. However, it is expected that these sectors will be addressed as future updates to these inventories are made.

3.3.3 *TRANSMISSION LINES*

Perhaps surprisingly, significant anthropogenic sources of N_2O in B.C. may be Transmission Lines, which are estimated to account for 30% of the anthropogenic provincial total or about 5% of

the overall total of N_2O (Figure 14). Notwithstanding that the methodology employed in this study needs to be substantiated from other sources, it is plausible that, given B.C.'s heavy reliance on hydro power from remote locations and the length of high voltage corridors required to deliver that power to industrial centres, Transmission Lines may very well be a significant source of N_2O emissions in B.C.

3.3.4 *INDUSTRIAL/LOMEI/FUEL COMBUSTION*

Stationary fossil fuel combustion sources, as represented by the Industrial Processes, LOMEI Point sources, and Fuel Combustion categories, account for a relatively small percentage of total N_2O emissions in B.C. (2%) and approximately 14% of the total anthropogenic emissions. The single largest industrial contributor to anthropogenic N_2O emissions is the Forestry sector which accounts for 10% of the total (Figure 17). The minor contributions of stationary fossil fuel combustion sources to overall N_2O emissions have been noted in recent literature. Original estimates of the contribution of these sources to increases in atmospheric N_2O are now widely considered to be too high as a result of sampling errors and have been significantly downgraded.

3.3.5 *OTHER SOURCES*

Wood Waste Incineration in wigwam burners is estimated to account for 5% of total anthropogenic N_2O emissions in the province, while the Application of Fertilizers is estimated to emit 4% of the anthropogenic total. Releases of N_2O from Commercial / Residential / Fuelwood Combustion sources and from the use of Anaesthetics and Aerosols may emit 1.5%, 2% of anthropogenic N2O, respectively.

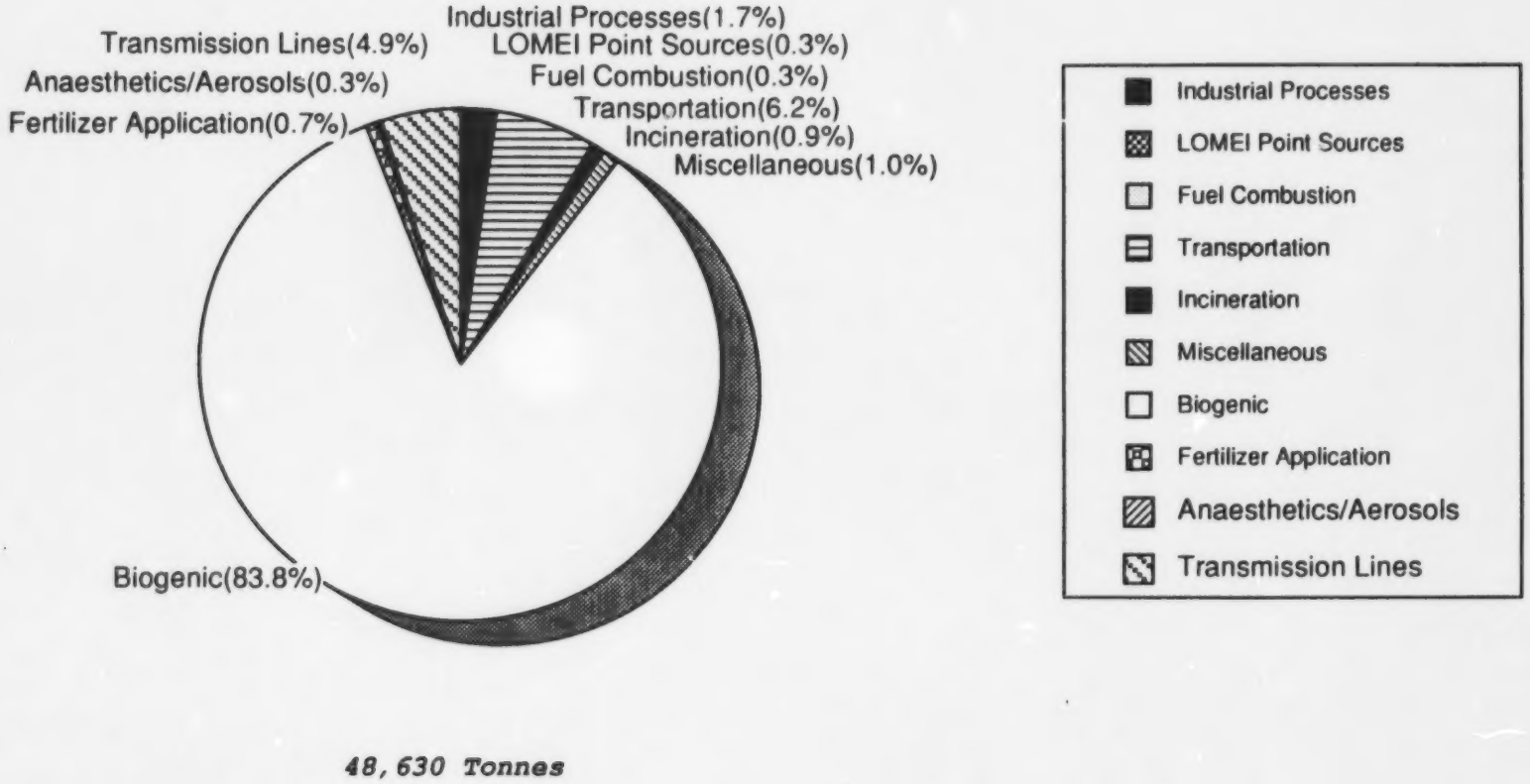


FIGURE 14. Total N_2O Emissions By Sector (1985)

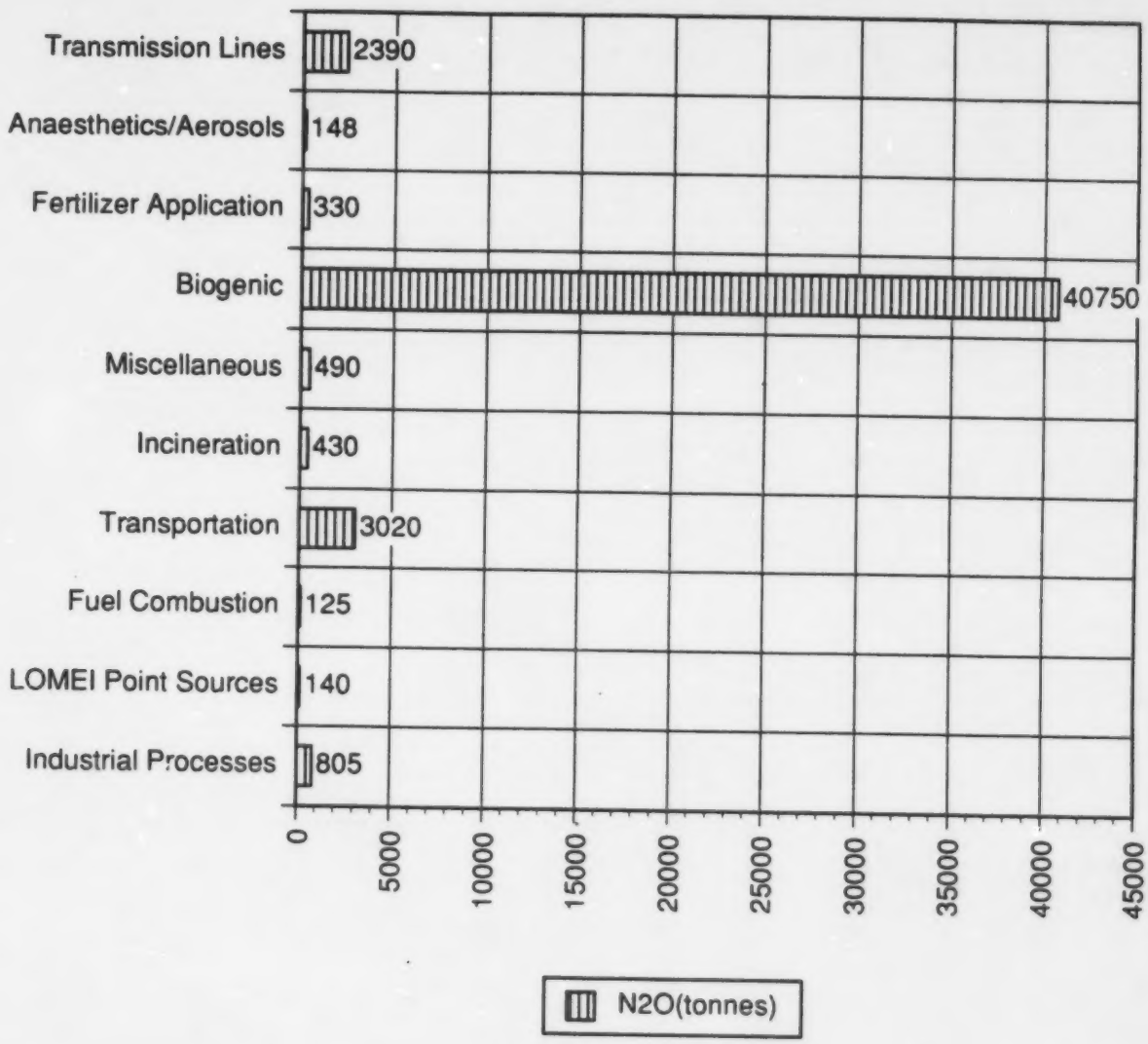


FIGURE 15. Total N_2O Emissions By Sector (1985)

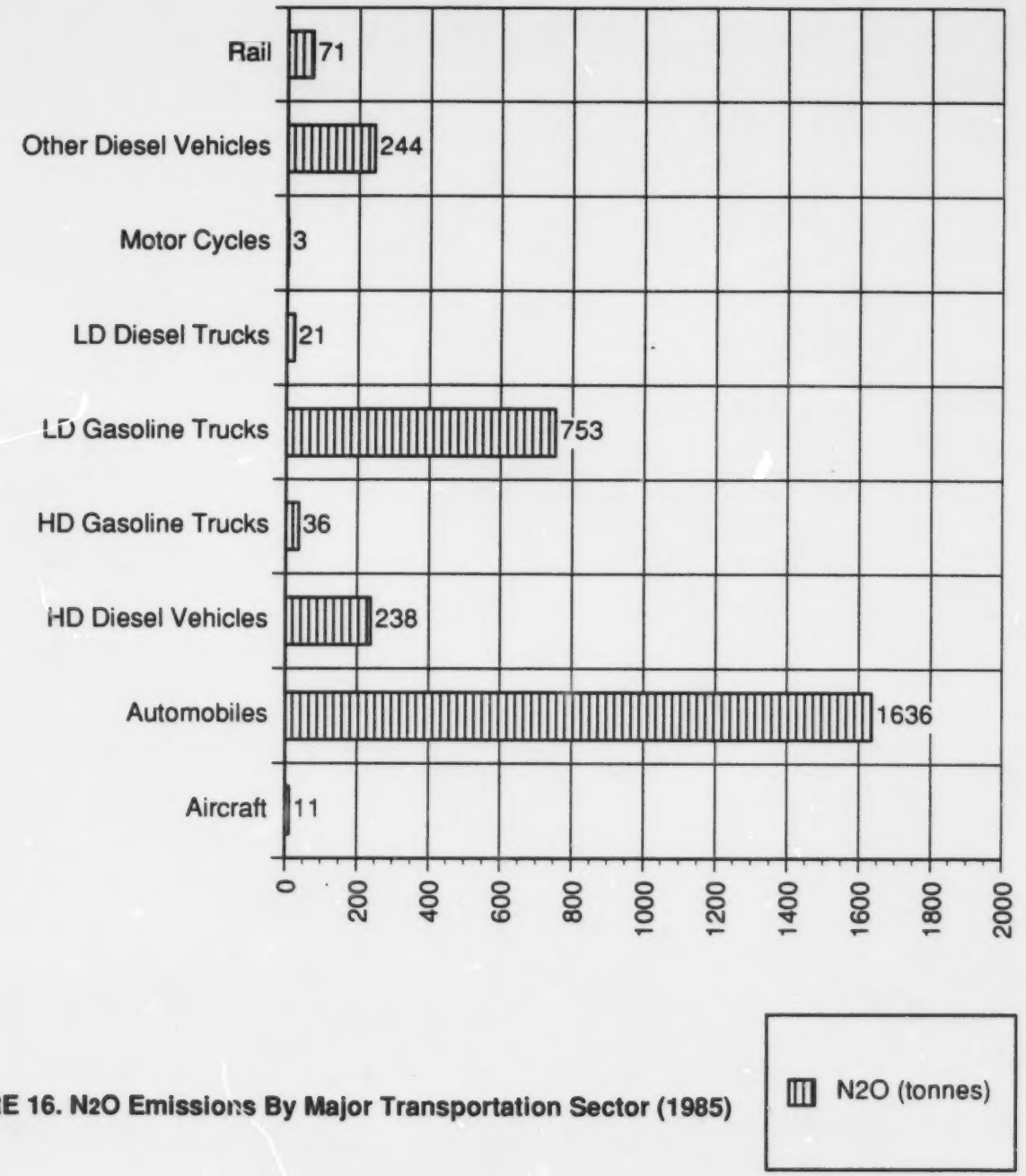


FIGURE 16. N_2O Emissions By Major Transportation Sector (1985)

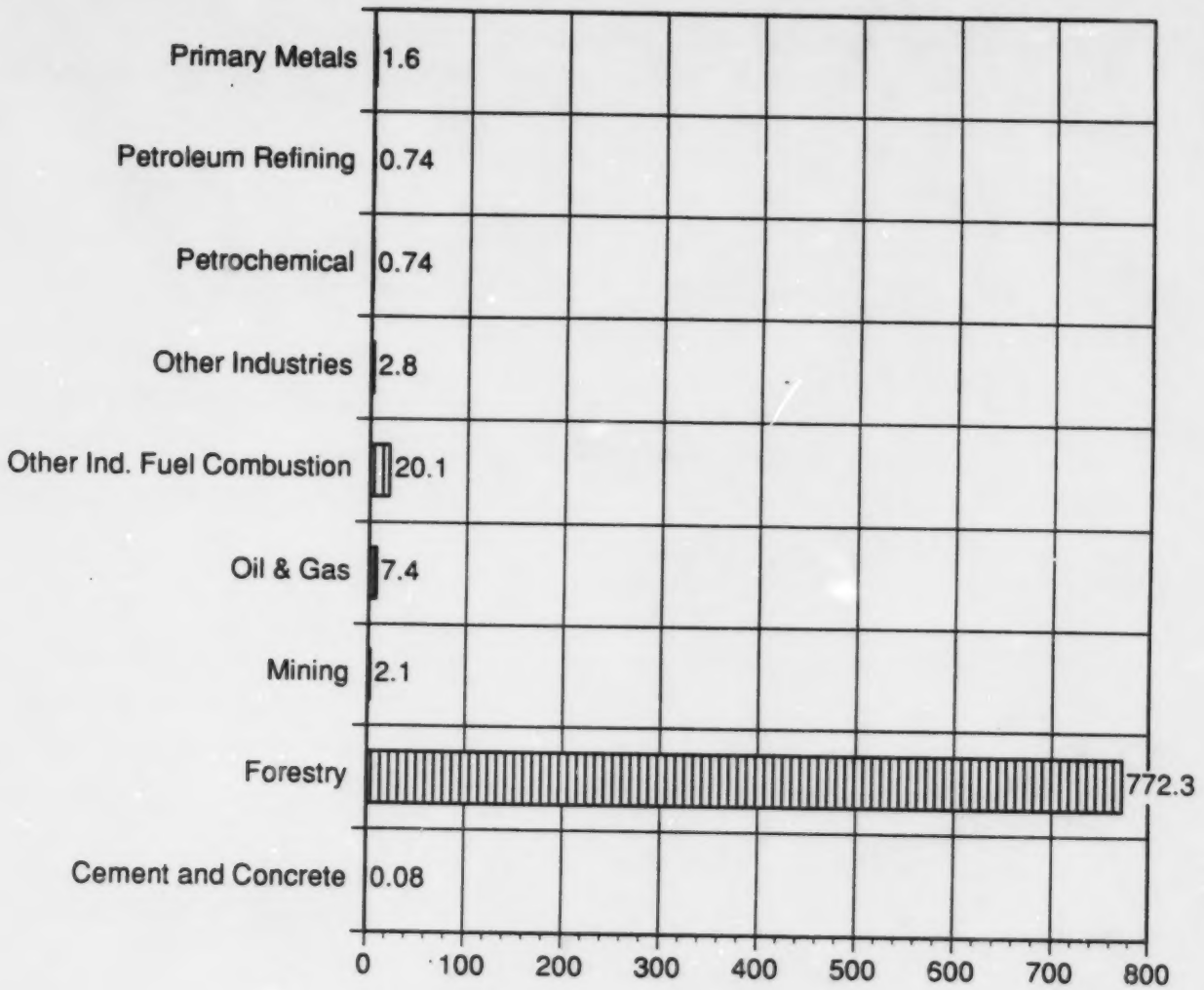


FIGURE 17. N_2O Emissions By Major Industrial Processess (1985)

3.4 Other Data Checks

For all area and mobile sources in B.C., data checks were performed by comparing emission estimates generated by RDIS for the Greenhouse Gases Inventory for the Lower Mainland grid square with data provided in the Lower Mainland Emission Inventory (LOMEI) for 1985 (GVRD, 1988a,b,c,d).

Several source sectors identified in LOMEI were modified so that equitable comparisons were possible. Since many sources in LOMEI were not identified by SIC code, this process was performed by educated guesses. The purpose of the above comparison is to provide a perspective on the range of values which may exist, not only as a consequence of uncertainties in spatial boundaries of emission inventories, but also because emission estimation methods differ. Although a detailed analysis of the reasons behind the above discrepancies is beyond the scope of this study, some general comments are offered:

NO_x emissions in the Transportation sector differ by a factor of 2. This is due to differences in fleet size and vehicle type breakdown. In addition, LOMEI estimated Transportation emissions using EPA's MOBILE 3 model, while RDIS used MOBILE 4. How significantly different the results of the two models are for a given pollutant is not known. Available information suggests that the change from MOBILE3 to MOBILE4 will have a greater influence on the estimate of VOC emissions than on the NO_x emissions (Alliance Corp., 1991).

Parameter	RDIS (Lower Mainland Grid Square)		LOMEI	
	NO_x	VOC	NO_x	VOC
	(tonnes)			
Transportation	99650	65885	46630	55610
Fuel Combustion	3373	2151	2974	351
Incineration	1150	1215	40	179
Miscellaneous	3689	40235	0	18943
Forest Fires	4702	25574	39	235
Slash Burning	3689	17449	5	31
Biogenic	0	34891	0	20347

The discrepancy between VOC emissions from Fuel Combustion sources is largely due to differences in emission estimates from Residential Fuelwood Combustion.

RDIS includes wigwam burners as Incineration area sources while LOMEI assumes that such wood waste disposal has been included as part of the point source emission inventory (based on waste). As an additional check, the total quantity of waste wood burned in B.C. (of which approximately 50% is assigned to wigwam burners) was determined in RDIS and compared with the quantity of waste wood estimated in the B.C. CO_2 Emission Inventory (EMPR, 1990). The]values were similar. This suggests that although the emission estimates for wigwam burners in B.C. appear appropriate, the RDIS method of distributing those emissions throughout the province is overly biased towards the population centres in the Lower Mainland. To produce a more representative gridded summary of NO_x/VOC emissions in the province, wigwam burner emissions assigned by RDIS to the Lower Mainland grid square were therefore deleted and reassigned to the remaining grid squares, based on the population distribution. Similarly, the discrepancy which exists in the Miscellaneous source sector is due largely to differences in emission estimates for Slash Burning. A comparison of RDIS fuel quantities with estimates provided in the CO_2 Emission Inventory suggests the total emission estimate is correct, but the distribution is again overly biased towards the Lower Mainland. Although base quantities could not be compared with other inventories for Forest Fires, it is assumed that a similar scenario exists for this category. For the Greenhouse Gases Inventory, emissions from Forest Fires and Slash Burning in the Lower Mainland were adjusted accordingly. With these corrections in place, the total emission estimates for the Lower Mainland grid square, with the exception of NO_x emissions in the Transportation sector, are similar to the estimates provided in LOMEI; while provincial emission totals remain intact and comparable to those of other inventories, as discussed above.

Emissions of biogenic VOCs in the Lower Mainland grid square compare favourably with estimates made in LOMEI, particularly considering the fundamentally different approaches taken for each inventory.

VOC emission estimates for Fuel Marketing in the Lower Mainland are also similar.

Furthermore, provincial VOC emission estimates for Fuel Marketing generally agree with estimates provided in the Canadian Petroleum Products National Emission Inventory (Levelton/RTM, 1991).

The above adjustments have been incorporated into the inventory and are reflected in the results reported in sections 3.1 to 3.3.

3.5 Ozone Inventory

Simplified estimates for manmade emissions in two regions of the province will illustrate the results of the approach to estimating ozone emissions described in Section 2.5. As shown by Liu et al.(1987), the product $\tau \cdot \Delta P$ is dependent on the average ambient nitrogen dioxide concentration. which can be taken for the purpose of this analysis as 0.5 ppb for rural B.C. and 10 ppb for the Lower Mainland area. The production of ozone from NO_x is more efficient at lower background concentrations of NO_x. With these assumptions, the ozone production per unit emission of NO_x is about 9 for the Lower Mainland and about 32 for the rest of B.C., in terms of tonnes of ozone produced per tonne of NO_x emitted.

The anthropogenic NO_x emissions for the two regions are

Lower Mainland:	107,906 t/y
Remainder of B.C.:	157,004 t/y.

Thus the corresponding ozone produced from these emissions in the two regions are

$Ozone_{Lower\ Mainland}$ = 107,906 $t(NO_x)/y$ x $9t(O_3)/t(NO_x)$ = 971 $kt(O_3)/y$.

$Ozone_{Rest\ of\ BC}$ = 157,004 x 32 = 5,000 $kt(O_3)/y$.

Alternatively, following the IPCC approach using Global Warming Potentials, the equivalent amount of ozone corresponding to the ozone portion of the CO_2 equivalents of NO_x and VOC emissions given in Table 3 can be back-calculated.

The GWP for ozone is not given directly in IPCC (1990), but its value may be determined relative to other greenhouse gases whose GWPs are provided. Using the latter approach, the GWP for ozone itself integrated over a 100-year period, as indicated in Section 3.1, is calculated to be about 1/255 of the GWP for CFC-11, so that the estimated GWP for ozone over this time period is 5. This results from the following calculation. On a mass basis, CFC-11 is about 2.6 times more effective than O_3, and the CFC-11 lifetime is 325 times longer (table in Chapter 1). The ratio of the

integrals in the equation which defines the GWP (see p. 26) over 100 years is 51 / 0.2 = 255. The GWP of CFC-11 over 100 years is 3500, so that the GWP of ozone is 3500 / 2.6 x 255 = 5.

From Table 3, the total ozone contribution to the CO_2 equivalents of NO_x and VOC emissions is 4130 kt/y for the province. The corresponding amount of ozone, then, is 4130 kt/y / 5 = 826 kt(O_3)/y. About 40% of this quantity is emitted in the Lower Mainland grid square, or 330 kt/y.

The Liu et al. and IPCC approaches give somewhat different numbers for the total production of ozone in the Lower Mainland grid square, 971 kt/y *versus* 330 kt/y. Nevertheless, it appears that the actual number ought to be of this magnitude, obviously with liberal error limits, based on the following analysis using existing air quality data for GVRD.

The above emission rates for ozone correspond to a range of 11,000 g/s to 32,000 g/s for the Lower Mainland grid square. The average atmospheric ventilation rate for the Lower Mainland taken from available meteorological data summaries is about 3,500 m^2/s. The above emission rate and this ventilation rate may be used to estimate the average ambient concentration, as follows. The characteristic dimension along which dispersion takes place is assumed to be the grid square length, 127 km.

$[O_3]$ ($\mu g/m^3$) = Emission rate (g/s) x 10^6 / [Ventilation rate (m^2/s) x Crid square length (m)]
= (11,000 to 32,000) x 10^6 / (3500 x 127 x 10^3)
= (25 to 72) $\mu g/m^3$
= (13 to 36) ppb

The mean annual ozone concentration in the GVRD portion of the Lower Mainland has been about (13 +/- 2) ppb over the past 12 years. If the background concentration is taken to be about 10 ppb (Concord/Levelton, 1989a), the total predicted by adding the above anthropogenic increments to the background would be 23 to 46 ppb as an annual mean. The observed mean is less than the low end of this range.

A similar approach to estimating whether the inventory emission rate for ozone is close to reality is as follows. For a steady state situation, the production rate equals the removal rate, 330 kt/y. The removal rate equals the mass of ozone divided by the residence time in the region. Thus, the following relationship exists between the concentration in the atmosphere above the region and the production rate:

$[O_3]$ = production rate x residence time / volume
= (3 x 10^{17} µg/y x 1 day) / (3 x 10^{13} m^3 * 365 d/y)
= 27 µg/m^3 = 14 ppb

This value is somewhat greater than the observed mean, once a background value is added. These indicators of the consistency of the current estimate of the annual ozone production rate in BC, then, suggest that the value of 330 kt/y is a reasonable approximation.

The calculation for the Lower Mainland grid square assumed an ozone productivity of 9 : 1 for each unit mass of NO_x emitted. The actual concentration of NO_x in some of the Lower Mainland area in which the ozone concentrations are monitored is higher than that which was used to estimate the ozone productivity ratio above. For example, the annual mean NO_x concentration in the GVRD monitoring network is about 20 ppb (as NO_2). The effect of this is to overestimate the quantity of ozone produced per unit quantity of NO_x. A more realistic estimate of the ozone productivity of a unit quantity of NO_x in the Lower Mainland would bring the two estimates closer to one another and the corresponding ambient air concentration range closer to the observed. Data are not available to estimate the ozone productivity of NO_x released in the Lower Mainland more accurately.

These estimates of the total quantity of ozone produced from precursors released in B.C., even given the significant uncertainty, indicate acceptable consistency of the ozone emission inventory for B.C. for the purposes of this project. More meaningful results will require much more detailed measurement and modelling data, which are beyond the scope of this project. The approximate agreement of the various methods of estimating total ozone emissions suggests that the result may be used as a reasonable preliminary estimate.

One can use the same approach to check the NO_x emission inventory estimate directly. The NO_x emission for the Lower Mainland grid square is about 3600 g/s. Using the same parameters and dimensions as for the ozone calculation above, the predicted increment to the annual average concentration of NO_x attributable to local emissions is then about 17 µg/m^3 (8 ppb). When this increment is added to the assumed background concentration of 10 ppb, the sum - 18 ppb - is very close to the observed value of about 20 ppb.

It is interesting to note that since the ozone productivity of a given quantity of NO_x is greater the lower the background concentration of NO_x, the Lower Mainland area emissions produce a proportionately smaller fraction of the provincial ozone than the rest of the B.C. - that is, about 16% (compared with 40% of the emissions). The emissions in the rest of the province are spread out over an area nearly 80 times larger than the Lower Mainland (on the inventory grid), so that the concentrations produced are low.

This analysis has not taken into account explicitly the significant production of ozone from biogenic precursors. It has been accounted for qualitatively in the background ozone concentration quoted above. The principal interest of this study is management of the anthropogenic emissions.

3.6 Gridded Summary of Emissions for B.C.

The two following maps (Figures 18 and 19) represent the gridded summaries of biogenic and anthropogenic emissions in British Columbia, calculated as CO_2 equivalents.

3.7 Discussion of Data Uncertainties

The intent of this discussion is to provide the reader with a quantitative and qualitative assessment of the degrees of uncertainty associated with the data compiled for the Greenhouse Gases Inventory.

Two common sources of error for all emission inventories are

a) use of inaccurate emission factor data, and
b) use of inaccurate base quantity data.

The degree of accuracy assigned to emission factors and to base quantity data is a function of their information sources. For example, emission factors determined by direct measurement of specific plant processes in the inventory are considered to be more accurate than broad, sector-based emission factors, which are in turn more accurate than those determined using educated guesses.

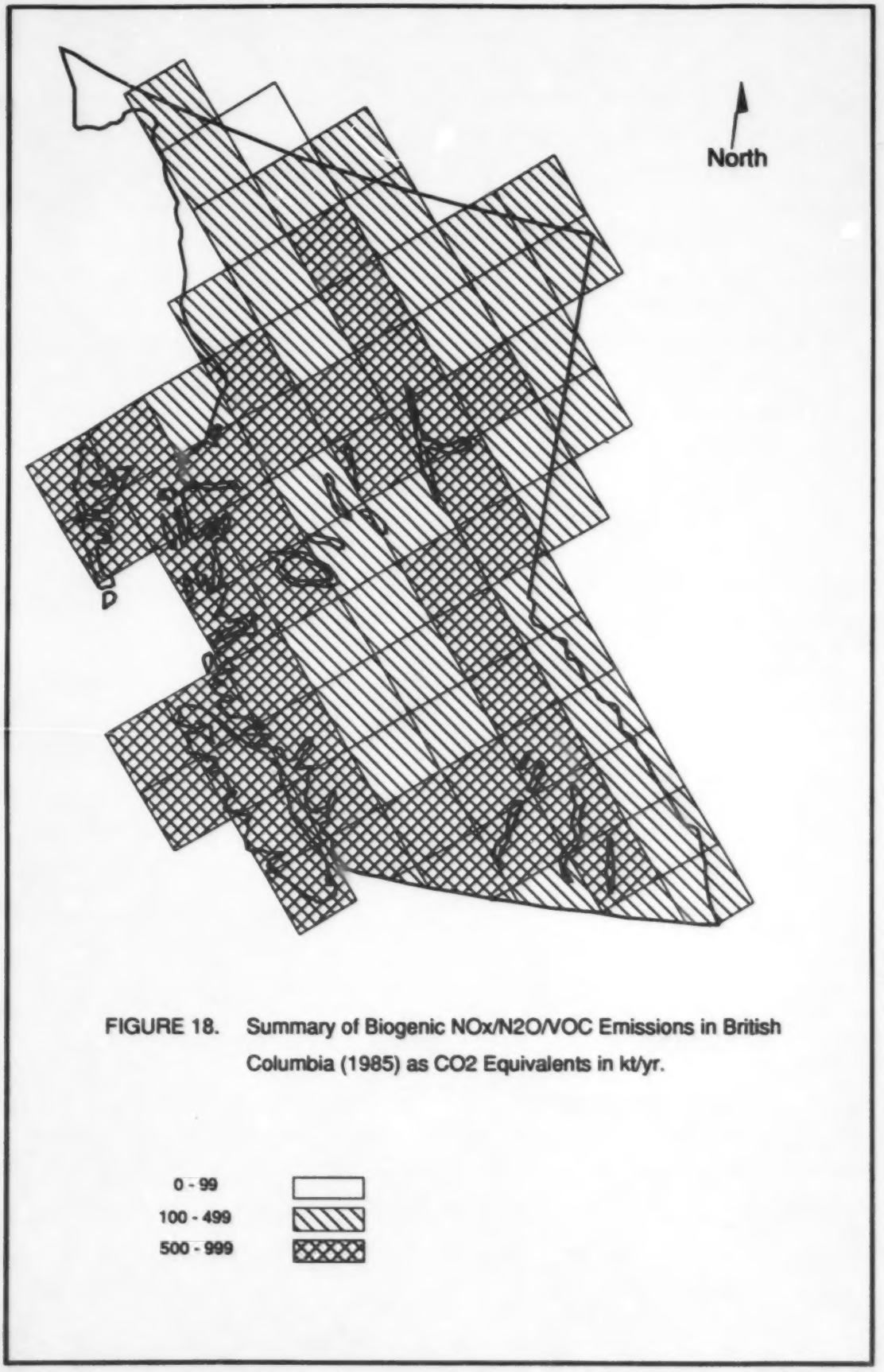


FIGURE 18. Summary of Biogenic NOx/N2O/VOC Emissions in British Columbia (1985) as CO2 Equivalents in kt/yr.

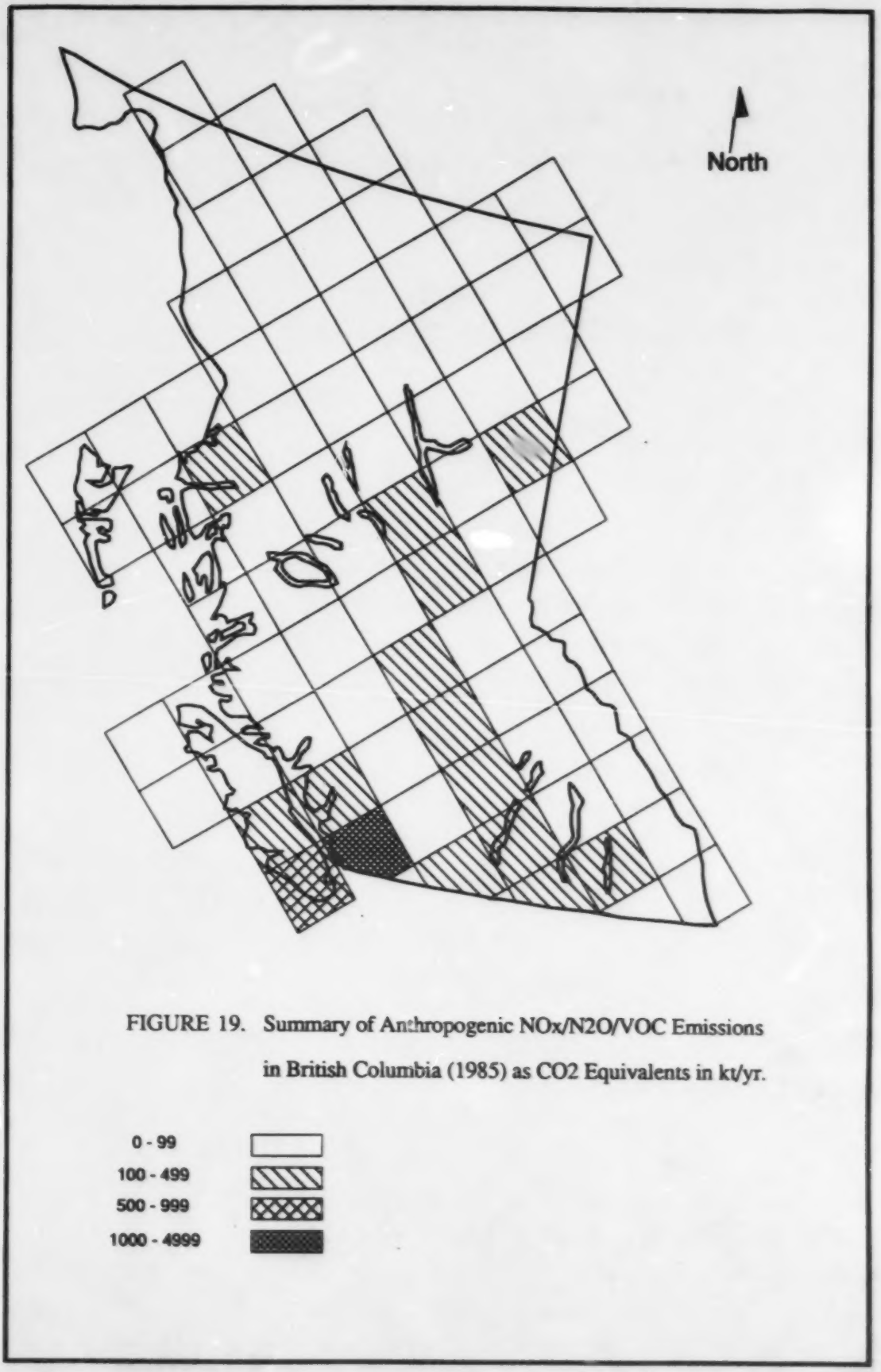


FIGURE 19. Summary of Anthropogenic NOx/N2O/VOC Emissions in British Columbia (1985) as CO2 Equivalents in kt/yr.

NO_x and VOC emission uncertainties

NO_x and VOC emission data in Environment Canada s Residual Discharge Inventory System (RDIS) were compiled from a broad range of sources and emission calculation methods, such as:

- source testing or measurements
- material balances
- U.S. EPA National Acid Precipitation Assessment Program (NAPAP) emission factors
- other emission factors
- adjusted permit data
- specific reports
- educated guesses
- other sources/methods

Since a data uncertainty analysis for RDIS was not provided at the time of this study, an overall estimate of uncertainty for the pollutants NO_x and VOC compiled within RDIS was calculated. The method used was to assign a subjective error range to each of the above mentioned calculation methods and then to estimate the overall error range for each pollutant by applying the equation:

$$e_t = \frac{\sqrt{\sum (e_i * E_i)^2}}{\sum (E_i)}$$

where:

e_t = overall relative error in the sum of emissions
e_i = relative error in each emission estimate
E_i = emission estimate in tonnes

The approach used here is very similar to the one applied in the 1985 LOMEI (GVRD 1988d) and the GVRD Air Management Plan - Stage I (Concord/Levelton, 1989b). The reader may refer to these references for a more detailed discussion regarding quantitative error analyses.

Although RDIS uses a greater number of emission calculation methods, the information sources are similar to those used in compiling the Lower Mainland Emission Inventory 1985. The representative error levels for the individual calculation methods were thus adopted from LOMEI, where possible.

The following table summarizes the error ranges assigned to each emission calculation method used in RDIS:

Calculation methods	Estimated range of uncertainty
Specific reports	± 20 %
Source testing or measurements	± 20 %
Material balances	± 30 %
U.S. EPA NAPAP emission factors	± 40 %
Other emission factors	± 40 %
Adjusted permit data	± 50 %
Educated guesses	± 100 %

These uncertainties were assumed to apply to each emission calculation and contaminant. In addition, the above error estimation methodology assumes that the emission estimates are unbiased, mutually independent and normally distributed, that no errors occurred during data entry, and that there are no missing data, no incorrect assignment of emission factors etc.

The overall uncertainties for all sources derived in this way for the Greenhouse Gases Inventory compiled within RDIS were ± 9% for NO_x and ± 10 % for VOC.

These numbers compare very favourably with the error estimates derived in LOMEI 1985, where the overall uncertainty for NO_x was estimated at ± 5%, the uncertainty for VOC at ± 3% (Concord/Levelton, 1989b). A direct comparison of Lower Mainland NO_x and VOC emission estimates generated by RDIS for the Greenhouse Gases Inventory with data provided in LOMEI 1985 (GVRD, 1988a,b,c,d), however, conveys a different picture (the differences between the two inventories were discussed at length in section 3.4.). Apparently, fundamental differences in the two inventories such as differing methods in assigning source sectors, detailed discrepancies within sectors, uncertainties in spatial boundaries of the inventories, differences in base quantities

and emission estimation methods and differing methods of allocating those emissions over the study area contribute to a much greater extent to the overall data uncertainty than is suggested by the above analysis. After reviewing several different approaches to estimating data uncertainty in emission inventories, it was concluded in Concord/Levelton, 1989b that serious limitations exist for determining uncertainties in emission inventories. In view of this and the above discussion, the above calculated values of uncertainty must, therefore, be considered with caution

N_2O emission uncertainties

The degree of uncertainty associated with fuel-based emission factors for N_2O and assumptions used to incorporate that data into RDIS is likely to be greater than the estimated uncertainties for NO_x and VOC. It is recognized in the literature that further research in determination of N_2O emission factors from fossil fuel combustion sources is required. Currently, widely accepted data is very sparse. Base quantity data used to estimate N_2O emissions from fuel-based sources were identical to the base quantity data contained in RDIS for NO_x emissions.

A still greater degree of uncertainty exists in estimating releases from sources categories compiled outside of RDIS and occurs as a result of broad-based selection of base quantity data. These categories include Biogenic NO_x/VOC/N_2O sources, Fertilizer Application, and Transmission Lines. For example, although VOC emission fluxes from vegetation are estimated using complex algorithms which incorporate a number of climatological and biological parameters, emission estimates for all of B.C. were based on data from only three representative B.C. climate stations. Similarly, NO_x and N_2O emissions from soils were estimated using soil parameters which are Canada-wide averages. Environment Canada (1981b) suggests that such emission data should be interpreted as order of magnitude approximations.

Ozone estimation uncertainties

The two distinct approaches used in this study to estimate the ozone inventory produced appreciably different numbers for total production of ozone in the Lower Mainland grid square - 971 kt/y versus 330 kt/y; a factor of 3 difference. Actual O_3 and NO_x monitoring data suggest, however, that the true value is probably closer to the lower end of this range.

Uncertainties associated with Global Warming Potentials

Another significant data uncertainty associated with the Greenhouse Gases Inventory is associated with the application of the IPCC Global Warming Potential (GWP) index to the inventory. Although this study incorporated the IPCC GWP index, a number of other global warming indices using quite dissimilar approaches also exist and are widely acknowledged in the scientific community. Whereas the IPCC GWP measures the instantaneous radiative forcing effects of emissions integrated over a specified (extended) period of time, Hansen et al (EPA 1990), for example, base their approach on the radiative forcing effects of estimated differences in atmospheric concentrations over a limited time frame. In other words, the former considers the future impact of current emissions and the latter considers the current impact of current emissions. Although apparently equally valid, the two approaches are conceptually different and yield somewhat different results. These differences are very small in the context of the overall uncertainties in this field (less than a factor of two). Nevertheless, both approaches are highly model-dependent and require continued research and refinement. In terms of assessing greenhouse gases in a policy context, the GWP approach is considered to be useful because of its ability to address the extended periods of time appropriate to long-term policy decisions. Given the above considerations, the summary of emissions in this Greenhouse Gases Inventory, considered as CO_2 equivalents, should only be interpreted as order of magnitude approximations.

4.0 PROJECTED INVENTORY OF NO_x/VOC/O_3 FOR THE YEAR 2005

Forecasts of the NO_x/VOC/O_3 inventories for the year 2005, were made consistent with the following scenarios:

I. No attempt is made by government to reduce NO_x/VOC emissions: and no attempt is made to reduce the formation of ground-level ozone;

II. Existing programs to reduce NO_x/VOC/O_3 are implemented; and,

III. Additional programs, consistent with those mentioned in the CCME NO_x/VOC Management Plan (1990) are implemented.

This activity relied heavily on material in the NO_x/VOC Management Plan (CCME, 1990), since a great deal of data analysis and interpretation went into its development.

4.1 Methodology

4.1.1 *GENERAL*

Because source controls for N_2O emissions reduction, other than net reduction in energy consumption, are largely unknown, N_2O emission forecasting for scenarios I and II were not performed. Notwithstanding this, a qualitative assessment is made regarding potential increases in N_2O emissions from the Transportation sector due to increasing use of NO_x/VOC control technologies, most notably, catalytic converters.

Emissions from Biogenic sources, Fertilizer Application and Anaesthetics/Aerosols Use are assumed to remain static. N_2O emissions from Transmission Lines would likely increase in proportion to power transmitted, but since the reliability of the model used to calculate the 1985 N_2O emissions from this source is not known, no attempt was made to project future emissions.

4.1.2 *SCENARIO I*

Much of the NO_x/VOC emissions forecast for scenario I can be estimated using B.C. Energy, Mines & Petroleum Resources (EMPR) energy demand forecasts (ARA, 1991). EMPR uses econometric modelling techniques to forecast future energy demand in B.C. The model first projects sector energy consumption, and then disaggregates this total to the various fuels according to market shares, subject to a variety of constraints and energy consumption relationships (EMPR, 1990). A detailed summary of EMPR sector-based energy forecasts is appended. The 1985 base data for the Greenhouse Gases Inventory were projected to 2005 assuming only changes in the fuel/energy consumption and population parameters. Since the energy forecast data are based on a 1988 base year, growth rates were adjusted by assuming linear extrapolation to 1985. Where direct EMPR data for several source sectors were not available, growth forecast data were obtained from B.C. EMPR s Carbon Dioxide Inventory for British Columbia (1990). These sectors include Municipal/Industrial Incineration, Wood Waste Incineration and Slash Burning. Finally, where appropriate, emission forecasts for other remaining source sectors were estimated by simply applying population growth forecast data for B.C. (B.C. FIN, 1991). These sectors include Dry Cleaning, Solvent Use and Surface Coatings.

4.1.3 *SCENARIO II*

Emission inventory forecasts to 2005 were made under the assumption that existing programs to reduce NO_x/VOC/O_3 as part of ground level ozone management are implemented, and that this strategy is congruent with their control as greenhouse gases. The projection was based on Emission Forecast 90-B (Pre-Plan) from the CCME NO_x/VOC Management Plan (CCME, 1990), where detailed descriptions of assumptions used in Plan 90-B may be found.

4.1.4 *SCENARIO III*

Emission inventory forecasts to 2005 were made under the assumption that proposed programs required to reduce NO_x/VOC/O_3 as part of ground level ozone management are implemented, and, again, that these changes are congruent with control of these substances as greenhouse gases. The projection used the Post-Plan scenario (National & Illustrative Regional Initiatives) from the CCME NO_x/VOC Management Plan (CCME, 1990). As above, descriptions of assumptions used for the Post-Plan scenario are presented in detail in the CCME document.

4.2 Results

A summary of NO_x/VOC emissions forecasted for B.C. following the three scenarios described above is presented in Table 4. A more detailed source sector listing of emission forecasts for each scenario is presented in Appendix E. However, since RDIS, EMPR and CCME-designated source sectors do not appear to be completely analogous, caution should be exercised in interpreting emission forecast data in any greater detail than the aggregated format that is presented in Table 4. Several source sectors, particularly those defined in the CCME document (e.g. scenario III), are either incomplete or not clearly defined. This is best illustrated by comparing 1985 source sector emission totals presented in Table 4 with source sector emission totals for the Greenhouse Gases Inventory summarized in Table 2. Consequently, emission forecasts for several source sectors are the result of rather arbitrarily assigned growth forecast rates.

Total anthropogenic NO_x emissions are expected to increase by approximately 57% in 2005 using scenario I parameters, but expected to decrease by approximately 16% and 21% under scenario II and scenario III parameters, respectively. The estimated decreases in NO_x emissions under scenarios II and III generally agree with those estimates provided in CCME (1990).

Total anthropogenic VOC emissions are expected to increase by approximately 2% in 2005 under scenario I, but expected to remain constant using scenario II parameters and expected to decrease by approximately 20% assuming scenario III parameters.

Within specific source sectors, the following comments are made:

The most notable trend in NO_x/VOC emissions between the various scenarios lies within the Transportation sector. Scenario I, by estimating emissions change simply on the basis of energy demand, predicts an increase in NO_x emissions by 41% and VOC emissions by 16% in 2005. By definition, scenario I assumes the state of control technologies and initiatives in 2005 is the same as it was in 1985. Scenario II, on the other hand, assuming existing and expected control technologies and initiatives are in place, predicts a decrease in NO_x and VOC emissions of approximately 27% and 31%, respectively. Scenario III predicts and additional 9% decrease in NO_x emissions and 24% decrease in VOC emissions.

In terms of the Greenhouse Gases Inventory, the forecasted decreases in NO_x/VOC emissions in the Transportation sector will likely be offset to a small extent by increased N_2O emissions. The

increase in N_2O emissions will occur largely as a consequence of widespread usage of NO_x/VOC control technologies, notably catalytic converters, in future motor vehicle fleets. Significant decreases in NO_x may be partially offset by increased N_2O emissions which will result. N_2O emissions from the Transportation sector under scenario II are estimated to increase by approximately 60% in 2005. In absolute terms, however, for each CO_2 equivalent increase in N_2O emissions from the Transportation sector in 2005, there will be a reduction of 1.7 CO_2 equivalents in NO_x and VOC emissions. N_2O emission forecasts for the Transportation sector were made using vehicle fleet breakdown data (by catalytic converter use) which were provided by Environment Canada (1991c) and estimated using MOBILE 4.

NO_x/VOC emissions within Industrial Processes remain consistent for all three scenarios. Notwithstanding the uncertainties inherent in the forecasting methodologies as well as introduced by the aggregation of source sectors into generic categories, the consistent NO_x/VOC emissions from the Industrial Processes sector suggest that industrial emission control technologies are generally offset by industrial economic growth.

Energy forecasts prepared by EMPR in scenario I estimate that significant growth in thermal power production will occur by year 2005. Consequently, significant increase in NO_x emissions from the Fuel Combustion sector is expected to occur (+ 423.5%). Large increases in secondary power production within industry is also forecasted; in particular conversion of wood waste to electricity by the forestry industry (Industrial Processes). This does not constitute an overall increase in the emission inventory, however, but rather a transfer of emissions from the Incineration sector (i.e. Wood Waste Incineration) to Industrial Processes.

The following apparent discrepancies in the forecast data are also noted:
Although scenario I predicts a large increase in thermal power generation, scenario II predicts a significant decrease in NOx emissions from the Power Generation sector. The inherent differences appear to be too large to be attributable to advances in control technology or fundamental differences in energy demand forecasts for B.C. Instead the data appear to suggest that CCME (scenario II/III) assumes a relatively heavier reliance in B.C. on hydro-electric power generation than that forecasted by EMPR (scenario I).

Scenario I (viz CO_2 Emission Inventory for B.C., 1990) predicts a significant decrease in Slash Burning. Scenario II (CCME), however, predicts a significant increase in NO_x/VOC emissions as a result of Slash Burning (the assumption therefore being that this activity has increased).

Table 4. NO_x/VOC Emissions Forecast Summaries

Sector	Actual Emissions (1985) (kT)		Forecast Emissions (2005) (kT)		% Change	
	NO_x	VOC	NO_x	VOC	NO_x	VOC
SCENARIO I						
Transportation	193.5	128.0	273.7	148.1	+ 41.4	+ 15.7
Fuel Combustion	12.3	4.5	64.4	9.6	+423.5	+113.3
Industrial Processes	47.6	58.9	69.6	86.1	+ 46.2	+ 46.2
Incineration/Miscellaneous	11.6	89.9	8.3	48.6	- 28.4	- 45.9
Total	**265.0**	**281.3**	**416.0**	**287.8**	**+ 57.0**	**+ 2.3**
SCENARIO II						
Transportation	193.5	128.0	141.4	88.0	- 26.9	- 31.3
Fuel Combustion	12.3	4.4	8.2	5.7	- 33.3	+ 29.5
Industrial Processes	47.6	58.9	73.7	89.4	+ 54.8	+ 51.8
Incineration/Miscellaneous	11.6	87.3	14.0	94.7	+ 20.7	+ 8.5
Total	**265.0**	**278.6**	**223.3**	**277.8**	**- 15.7**	**- 0.3**
SCENARIO III						
Transportation	186.8	98.0	119.3	44.0	- 36.1	- 55.1
Fuel Combustion	12.3	-	5.8	-	- 52.8	-
Industrial Processes	47.6	-	69.3	-	+ 45.6	-
Industrial Proc./ Fuel Comb.	-	63.3	-	85.3	-	+ 34.8
Miscellaneous	-	43.4	-	35.1	-	- 19.1
Total	**246.7**	**204.7**	**194.4**	**164.4**	**- 21.2**	**- 19.7**

4.3 Projected Changes in Ground-level Ozone

The NO_x/VOC Management Plan (CCME 1990) provides estimates of reductions in peak (one-hour averages) ozone concentrations which would be achieved by reductions in NO_x and/or VOC emissions. The annual average concentration of ozone, however, is the parameter of interest respecting ozone as a greenhouse gas, since the total annual contribution is important. This section addresses how that quantity is expected to change over the projection period.

Results of ambient monitoring for ozone (primarily in the GVRD and vicinity) show that the annual average O_3 concentration at all GVRD stations, for example, has remained stable at about (13 +/- 1) ppb since 1978. This occurred despite appreciable fluctuations in the frequency of high hourly O_3 levels (i.e., exceedances of air quality objectives). Similarly, projections of expected peak ozone levels in the GVRD to the year 2005 (Concord/Levelton, 1989a) indicated that these levels would remain stable, in the absence of management measures. The impact of the measures of the NO_x/VOC Management Plan applied to the Lower Fraser Valley is predicted to lower the peak (one-hourly) O_3 concentration by 20 to 30% at both Vancouver and Chilliwack. The range of peak O_3 concentrations at the two locations are estimated as follows.

	Peak Ozone Concentration (ppb)	
	Pre-Plan (1985)	Post-Plan(2005)
Vancouver	60 - 210	45 - 160
Chilliwack	80 - 120	60 - 90

The changes in peak ozone concentration are predicted to result in proportionately greater reduction in the number of hours during which the ozone concentration would exceed the Maximum Acceptable Ambient Air Quality Objective - reductions of the order of 50%. Since the number of hours during which the objective is (and is expected to be) exceeded is (will be) in the range of 10 - 25 hours per year, however, the annual mean will not be significantly affected by these considerable reductions in the exceedances of the objective. The annual mean is unlikely to drop by more than 10% with these anticipated changes.

The important implication of this relationship between peak and mean parameters of the ozone concentration distribution (in the GVRD area or elsewhere) is that the measures to control the direct effects of ground level ozone (human health and vegetation damage), which are related to the peak concentrations, will not apparently have a significant effect on total ozone production. Thus, drastic reductions in precursor emissions beyond those required to reach acceptable peak ozone levels would be required to control ground level ozone as a greenhouse gas.

5.0 MANAGEMENT MEASURES

5.1 Introduction

5.1.1 *STUDY SCOPE*

One of the objectives of the NO_x/VOC/O_3 Greenhouse Gas Project is to recommend measures for the reduction of this class of pollutants. This part of the study report addresses management options. The study task involved identifying possible measures as well as evaluating them. The overall purpose was to assess which measures may be readily implemented/adopted and which may require more proactive actions by the provincial government.

However, we emphasize that the conclusions of this study do not constitute a management strategy for controlling NO_x/VOC/N_2O emissions; rather they offer ideas on a number measures. To arrive at a strategy, measures must be combined to minimise internal conflicts and emphasize synergies among measures. Most importantly, the measures for NO_x/VOC/O_3 must be assessed within the context of an overall Greenhouse Gases Strategy.

The results of this study -- which was very much an exercise in isolation -- must be meshed with results of the other three studies in the Greenhouse Gases Project to ensure that measures for some pollutants do not increase other pollutants or, if they do, that trade-offs between pollutants are explicit. This task remains with the Greenhouse Gases Project Committee and lies outside the Terms of Reference of this study[1]. The review of management measures addresses anthropogenic sources only.

5.1.2 *OVERVIEW OF APPROACH*

The analysis of management measures was carried out as follows:

1. Identification of key source sectors, based on the inventory documented above;

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[1] The narrow perspective for this study was chosen so that the universe of possibilities for each gas could be addressed without prejudgement or exclusion on the basis of its impact on other pollutants. This approach means that, in the next stage of the project, trade-offs between pollutants will be obvious and explicitly addressed, resulting in a more robust strategy for the province.

2. Identification and review of NO_x/VOC management plans in other jurisdictions, supplemented by sector studies and general air quality plans as needed;

3. A limited number of interviews with environmental planners in other jurisdictions;

4. Analysis and comparison of measures (to the extent possible) based on three main criteria:
   cost-effectiveness (i.e., cost per tonne of emissions reduced)[2]
   potential reductions in NO_x/VOC/N_2O
   non-quantifiable factors, such as public attitudes towards the measure, technological risk, infrastructure requirements, etc.

The categorization of measures necessarily involved some subjective judgement. In making those judgements, qualitative information from a variety of studies was considered.

This chapter is structured as follows. In the remainder of this introductory section, major emission sources and geographical distributions are discussed. In Section 5.2, comprehensive NO_x/VOC management plans in other jurisdictions are outlined and Section 5.3 identifies specific management measures by source. Section 5.4 draws summaries the analysis.

Three appendices support this chapter. Appendix G presents summaries of other relevant air quality management plans; Appendix H provides an overview of the role of alternative fuels in reducing emissions; and Appendix I defines certain management measures.

5.1.3 *KEY SOURCE SECTORS*

The greenhouse gas emission inventory presented in previous sections identifies emissions by source sector. For example, Figure 4 in Chapter 3 illustrates emissions for the transportation sector. However, for the analysis of management measures, the sectors must be modified slightly to group sources that would be affected by a given set of measures. In the transportation sector, for example, measures that control emissions from air transportation will have little bearing on control of emissions from road transportation.

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[2] Cost-effectiveness is calculated by dividing the cost of the measure by the expected reductions in NO_x/VOC. The resulting cost-effectiveness statistic is expressed as dollars per kilogram NO_x/VOC/N_2O reduced. The lower the cost per kilogram reduced, the more attractive the measure. Cost-effectiveness values can be negative when the costs of the measure are more than compensated by the monetary benefits; that is, they pay for themselves.

To facilitate the analysis of management measures, we have regrouped source sectors. Table 5 provides an overview of the major sources[3]. The five largest sources -- the Tier I sectors -- account for about 70% of total NO_x/VOC/N_2O emissions in the province (on a CO_2 - equivalent basis). The emissions profile is further dominated by road transport, accounting for 41% of all emissions.

Slash burning and transmission lines account for an additional 18% of total emissions (9% each) and off-road transportation, which is made up of industrial vehicles and off-road use of gasoline, accounts for a further 6% of emissions[4]. Pulping (kraft process) contributes substantially less (i.e., 3% of provincial emissions).

Tier II sectors include sectors that have received somewhat more attention in the policy arena (such as gas marketing, solvents, surface coatings) as well as the largest sectors after the Tier I sources. It is worthy to note that the "higher profile" sources such as gasoline marketing in fact contribute less than 2% of total emissions.

The breakdown of emissions summarized in Table 5 determined priorities for the analysis of management measures. Specifically, considerable attention was devoted to road transportation and, through it, off-road transportation. Slash burning and kraft pulping were also addressed. Less attention was given to transmission lines partly because management measures were not extensively discussed in the literature. Tier II sources were essentially excluded from consideration except to report findings of specific studies on these sources.

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3 This section has been revised for a CO_2 equivalency factor of 7 rather than 40 tonnes CO_2 per tonne NOx. The revision did not affect the grouping of sources into Tier I or Tier II and, therefore, did not substantively affect the discussion of management measures. The revision does, however, further broaden the source base. For example, road and off-road accounted for 68% of total emissions prior to revision, compared with 47% after the revision. Conversely, a wide variety of much smaller sources, reflecting the VOC inventory, have increased their share.

4 Air, rail and marine transportation are grouped individually and account for about .6%, 1.9%, and 0.8% of total emissions respectively, province-wide.

TABLE 5. NO_x/VOC/N_2O Emissions by Sector (kt)

	NO_x		VOC		N_2O		CO_2 Equivalents	
	CO_2 equiv.	% NO_x[a]	CO_2 equiv.	% VOC[a]	CO_2 equiv.	% N_2O[a]	kt	% anthropogenic
TIER I SECTORS								
Road Transportation[b]	955	51	1,240	40	780	34	2,975	41
Slash Burning	65	3	485	15	140	6	690	9
Transmission Lines	-	-	-	-	690	30	690	9
Off-road transportation[c]	260	14	95	3	70	3	425	6
Kraft Pulping	110	6	-	-	105	5	215	3
Sub-total	**1,390**	**75**	**1,820**	**58**	**1,785**	**78**	**4,995**	**69**
TIER II SECTORS								
Surface Coating	-	-	155	5	-	-	155	2
Rail Transporation	110	6	10	<1	20	<1	140	2
Oil & gas industry (incl. petroleum refining)	80	4	60	2	2	<1	140	2
Sawmills	30	2	-	-	105	5	135	2
Gasoline Marketing	-	-	135	4	-	-	135	2
Solvent Use	-	-	130	4	-	-	130	2
Sub-total	**220**	**12**	**490**	**16**	**130**	**6**	**635**	**12**
Other	250	13	830	26	365	16	1,445	20
Total	**1,860**	**100**	**3,130**	**100**	**2,285**	**100**	**7,275**	**100**

a Percent anthropogenic sources.
b Includes all road transportation plus public administration & pipeline vehicles.
c Includes off-road use of gasoline & most diesel - powered industrial vehicles.
Note: Numbers may not add due to rounding
Source: Appendix D

Geographic Considerations

In addressing NO_x/VOC/N_2O emissions, different sources may necessitate different sets of management measures in different parts of the Province. To assess the importance of this concern to the management strategy, gridded summaries of emissions for some of the key sources were prepared. These are presented as Figures 20 and 21.

Figure 20 indicates the distribution of road transportation and off-road transportation emissions.Based on population distribution, the emissions are concentrated in the Lower Mainland. Figure 21 indicates the distribution of emissions from pulping as relatively concentrated in the southern coastal and central areas of the Province; however, the scale of pulp and paper emissions is about 10% that of the transportation components.

Gridded summaries were not prepared for slash burning or transmission lines, which the database distributes evenly across the Province.

From Figures 20 and 21, we can conclude the following:

- management measures to control NO_x/VOC/N_2O emissions are most relevant for the Lower Mainland where transportation emissions are highest[5],

- measures to control pulping emissions constitute a Province-wide strategy.

In short, the most important management measures will be those targeted to the Lower Mainland. Any spill-over effects of these measures (e.g., driver awareness) to other regions will have benefits for reducing greenhouse gases; however, efforts outside the Lower Mainland should be set as a second or even third priority (after pulping measures).

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5 From the perspective of greenhouse gases only, the location or concentration of emissions is not relevant; reducing per vehicle emissions from road transportation in the Prince George area is as important as in the Lower Mainland. This is not the case when NOx/VOC management is driven by tropospheric ozone problems, where peak periods and concentrations of emissions determine health impacts. However, the concentration of emissions is important when designing and implementing a management tool such as public education; in this case, the gridded summary clearly tell us that most effort should be devoted to the Lower Mainland where the greatest number of "emitters" can be contacted.

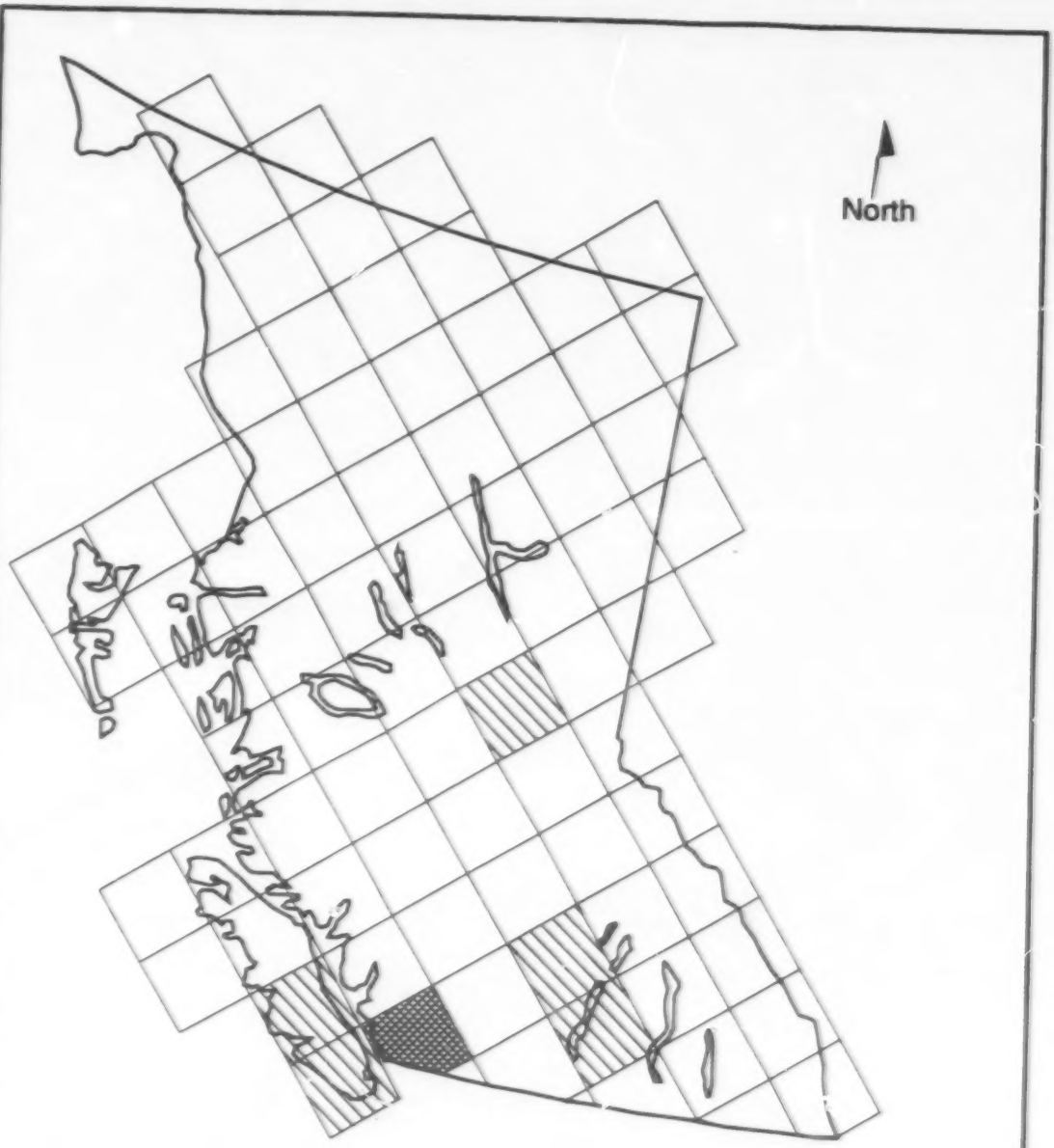

FIGURE 20. Summary of Emissions from Road, Offroad* and Rail Transportation in British Columbia (1985) as CO2 Equivalents in kt/yr.
(* Excludes Aircraft, Snowmobiles and Marine Vehicles).

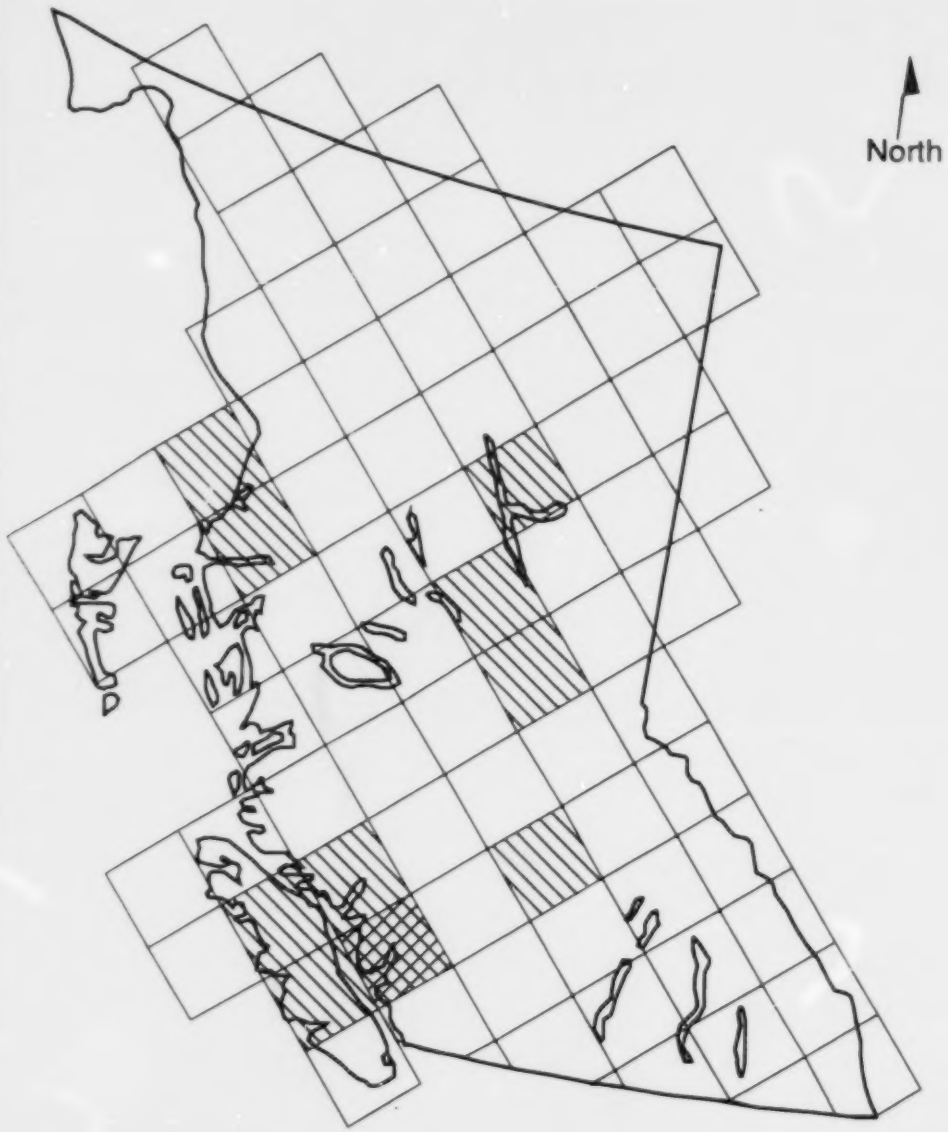

FIGURE 21. Summary of Emissions From the Pulp and Paper Industry in British Columbia (1985) as CO2 Equivalents in kt/yr.

5.1.4 *INFORMATION CONSTRAINTS*

Our review indicates that there are serious information constraints in published documents summarizing the efforts of other jurisdictions.

First, many plans consider NO_x and VOC only in conjunction with other gases. For example, the cost-effectiveness ratings found in the California air quality management plan lump together the emission reduction cost for all gases being considered. There is no separate costing of NO_x/VOC (although there is a separate emission reduction target for each gas). All of the traffic management plans also fall into this category, as they generally target vehicle emissions of all types rather than NO_x/VOCs specifically.

Second, many of the factors that one would like to take into account in rank ordering various measures are not discussed in these publications. Some do not set any target emissions or emission reductions at all; others do not separate out NO_x/VOCs (as noted above). Only one plan (the GVRD gasoline marketing plan) discusses costs for these gases explicitly; most discuss general user costs of the entire plan, or costs aggregated over all gases. Costs of government regulation and enforcement are not generally considered and many do not discuss costs at all.

Most plans have no discussion at all of barriers to implementation such as public resistance, enforcement difficulty, or lack of technological solutions although in some cases barriers may be inferred from common sense or from other sources (e.g., comments made on the draft Canadian NO_x/VOC plan by the Canadian Automobile Association or the Canadian Motor Vehicle Manufacturers Association).

Third, the background data underlying many of the results are not available in the reports nor are they readily available from administration staff. Cost calculations, for example, are not explained in enough detail to allow comparisons among reports: for example, discount factors are unknown, government subsidies are not discussed and product development costs are not defined. Similarly, many plans present estimates of emission rates or per capita exposures at present and assuming plan implementation. These estimates are by necessity extremely complex and far too lengthy for inclusion in the public documents, but even the basic assumptions may not be discussed (e.g., mix of vehicle types and fuels; assumed population shifts).

Fourth, many studies make clear that there are important gaps in our understanding of emissions.

Basic emissions inventories are not available in many jurisdictions, and calls for such inventories feature prominently in many plans of action. The CCME and California reports are similarly clear that meeting future targets depends heavily on technologies that do not now exist.

While some of these problems would be reduced through a detailed review of the background studies prepared for other plans, this is outside the scope of this study. In the review and ranking of measures found below, then, we have essentially taken published information at face value and, where necessary, have made reasonable assumptions about factors not discussed in the reports that will likely influence the effectiveness of each measure.

5.2 Overview of Comprehensive NO_x/VOC Plans

Perhaps the most important lesson learned during review of other plans designed to improve air quality is that relatively few of them specifically target NO_x and VOC.

Because most studies concluded that vehicles -- and particularly automobiles -- are the most copious producers of such gases, many plans incorporate a multitude of measures designed to alter and control traffic patterns and vehicle use. In many cases, such plans do not specifically target any emission gas (either by type or in terms of emission level). An example is the report of the City of Vancouver's Task Force on Atmospheric Change. It makes recommendations regarding transportation, land use, and energy conservation and efficiency; sets a target of a 20% reduction of CO_2 emissions by 2005; deals with SO_2 and ozone-depleting chemicals; and states that "related pollutants" should be brought within federally determined acceptable levels. However, it does not identify the impacts of the proposed measures on specific gases (e.g., NO_x, VOC) nor does it estimate implementation costs or other indicators by which each measure might be ranked.

Other reports target specific processes or gases that are a limited portion of the greenhouse gas problem. For instance, the Vancouver Oxidants Study proposes controls for VOCs derived from gasoline marketing but no other source. Similarly, the GVRD Air Management Plan - Stage I discusses possible control measures for this source of VOC but concludes that the NO_x problem requires further investigation.

We have identified only two plans that comprehensively address the NO_x/VOC gases: the South Coast Air Quality Management Plan (AQMP) for the South Coast Air Basin of California, and the

Canadian Council of Ministers of the Environment (CCME) Management Plan for NO_x and VOCs. The former plan incorporates explicit discussion of NO_x and VOC impacts associated with each measure proposed (it also discusses other gases) and is a model for many of the other studies and plans currently being carried out across North America. The latter, of course, focuses on the specific gases of interest in this study.

In this section of the report, these two plans are summarized. Brief overviews of other relevant initiatives are also presented.

5.2.1 *CCME MANAGEMENT PLAN FOR NO_x AND VOC*

The CCME plan was developed in consultation with stakeholders over the period August, 1989 to June, 1990 and, after review, was finalized in November, 1990. It incorporates a three phase plan to control NO_x and VOCs in order to resolve ground-level ozone problems in Canada by 2005. Phase I is designed to create a strong prevention program nationally, supplemented by a comprehensive set of remedial actions in regional areas having the worst ozone problems. Interim NO_x and VOC reduction targets will be established in federal/provincial agreements for the three ozone non-attainment areas (Lower Fraser Valley, Windsor-Quebec Corridor, and Southern Atlantic Region), but they are not expected to fully solve the problem.

Subsequent Phases II and III will define targets for the years 2000 and 2005 and the measures required to meet them, with the aim of having all parts of Canada consistently meet the air quality ozone objectives by 2005[6]. Included in the plan is consideration of the effects of transboundary flows of pollutants from the U.S. into Canada. A series of studies is also identified to increase technical knowledge of certain emissions related to ozone production.

There are dozens of individual national and regional measures proposed in each of three fields: energy conservation and product control (e.g., energy efficiency in buildings for NO_x and reduction of solvent emissions for VOCs); consumer choice and lifestyle (e.g., education on driving habits for both gases); and source control (e.g., NO_x controls for vehicles and chemical plant process controls for VOCs). These measures will be discussed in more detail in Section 5.3.

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6 As indicated earlier in the report, relevant management measures for the Greenhouse Gases Strategy reduce average annual emissions rather than peak period emissions. In drawing from the CCME Management Plan, we have excluded measures related to peak period emissions only.

5.2.2 *THE U.S. CLEAN AIR ACT AMENDMENTS OF 1990*

The amendments to existing air quality legislation are designed to curb acid rain, toxic air emissions, and urban air pollution. The latter goal is relevant to this study, as some amendments specifically target VOC and NO_x emissions. There are many individual measures within ten titles.

Three titles are particularly relevant to this study:

i) Title I -- Non-attainment

This title divides cities into six categories according to their attainment or non-attainment status regarding ozone. Specific yearly percentage reduction targets for NO_x and VOC are set for each category (more seriously non-attaining areas have lower yearly targets), with some flexibility in terms of technical feasibility and NO_x substitution allowed after six years. Standards for CO and PM_{10} are also included in this title.

Non-attainment areas must correct their existing Reasonably Available Control Technology (RACT) and Inspection/Maintenance (I/M) programs, and there are various increasingly stringent requirements for these programs depending on the severity of the non-attainment. For example, as the severity of the problem increases, control must be exercised on increasingly small sources, emission rates for NO_x even on "clean fuels" lowered, or peak hour traffic controls implemented. Various sanctions are in place for non-complying states.

Federally, control technology is required for NO_x and VOC sources of 25 tons (23 tonnes) annually or more. The EPA issued provisions related to emissions from aerospace coatings, shipbuilding and repair, marine vessels during unloading of petroleum products, and consumer products.

ii) Title II -- Mobile sources

Two tiers of stringent vehicle tailpipe standards were introduced. Tier I is to be phased in during 1994-1996 and Tier II will be implemented if deemed necessary and cost-effective by the EPA. Most emission standards will relate to 100,000 miles of vehicle use.

By 1998, all centrally-fuelled fleets of 10 or more vehicles in the 26 most serious non-attainment

areas will have to buy 30% of their new vehicles satisfying even more restrictive tailpipe standards for VOC and NO_x (30% of the usual VOC standard and half the usual NO_x level), unless such vehicles are not offered for sale in California. By the third year, 70% of new vehicles will have to comply.

In 1996, 150,000 clean fuel cars must be sold in California in a pilot program, increasing to 300,000 by 1999. These cars must meet VOC standards half that of the national level, and the standards may be met with any combination of vehicle technology and cleaner fuels. Other states can "opt in" to this program, but only through incentives (not sales or production mandates). Reformulated gasolines are required in the nine worst ozone areas beginning in 1995: VOC reductions of 15-25% are required. On-board refuelling controls may be required and gasoline Reid Vapour Pressure (RVP) will be lowered to 9 psi in most of the country (lower levels may be set in warm non-attainment areas). Off-road engines may be regulated if the U.S. EPA determines they contribute to air pollution. At a minimum, locomotive emissions will be controlled.

iii) Title III -- Operating permits

State permit programs will be required for Title I major sources as well as relevant sources in other titles of the Act. These permits may be for up to 5 years and must include all Clean Air Act requirements applicable to the source as well as a schedule of compliance, monitoring, and reporting.

5.2.3 *THE SOUTH COAST AIR QUALITY MANAGEMENT PLAN (CALIFORNIA)*

The South Coast Air Quality Management Plan (SCAQMP) is designed to bring the South Coast Air Basin into compliance with federal and state air quality standards and to meet California Clean Air Act (CCAA) requirements. It is a comprehensive set of measures to address toxic emissions, global warming, and ozone depletion, as well as the federal and CCAA air quality requirements. It also takes into account the differences between summer and winter emissions. Specific gases considered are NO_x, SO_x, PM_{10} (particulate matter), CO, and ROG (reactive organic gases; comparable to our definition of VOC). It generally is stricter than the federal Clean Air Act.

Modelling is based upon assumptions about the impact of new automobile emission standards introduced since 1988, as well as assumptions about the mix of vehicles that will be on the road in 2010. These assumptions include: electric vehicles will account for 17% of all passenger cars and

30% of buses; alternative fuels will be used in 33% of passenger vehicles and 70% of buses; and so forth.

The CCAA requires that all proposed measures be ranked in order of their cost-effectiveness (cost per ton per average annual day). Costs are to the user, including obtaining, installing, and operating the control measure. In addition, the CCAA requires ranking according to criteria of efficiency (pros and cons of the measure), total emission reduction, enforceability, equity to users and residents, legal authority, public acceptability, rate of emission reduction (speed of the impact), and technological feasibility. The main report, unfortunately, contains information only on emission reduction and estimated costs, but not necessarily on both for each measure/strategy.

The SCAQMP is structured into three tiers. Tier I identifies specific control measures for which the technology currently exists. Many of these are in fact already in place under earlier versions of the SCAQMP. They consist mainly of stationary source controls that will be the subject of district rules, motor vehicle emission standards, and federal programs to reduce emissions from sources under federal jurisdiction. Tier II measures are mostly composed of extensions or more stringent applications of Tier I measures or requiring additional research (e.g., regarding solvent reformulation and non-polluting power generation and energy storage). Tier III goals are tied to substantial technological advancements and breakthroughs over the next two decades: Tier III calls for extremely low vehicle emissions. Further detail is found in Section 5.3.

5.2.4 *NORTHEAST STATES FOR COORDINATED AIR USE MANAGEMENT(NESCAUM)*

NESCAUM is an association of the air quality control divisions in eight American northeast states. Its purpose is to promote cooperation and coordination of air quality technical and policy issues among the member states. To accomplish this, NESCAUM sponsors frequent training programs, participates in national debates, assists in exchange of information, promotes a variety of research initiatives, and coordinates technical committees of the member states regarding control strategies and technologies.

NESCAUM was formed in 1967, originally to deal with emissions from large power plants on or near state borders. Among the many air quality topics it now addresses is that of ozone attainment. Each of the member states administers pre-construction review of possible new pollution sources and modifications of existing sources. The minimum size of source varies from state to state, but all require sources to review available control technologies and select the Best Available Control Technology (BACT). For major new sources or major modifications in ozone non-attainment

areas, the control technology required is Lowest Achievable Emission Rate (LAER). There are formal guidelines for both applicants and agencies for each of the BACT and LAER reviews, designed to promote consistent analysis of proposed control technologies and consistent review of applications. Control technologies are ranked in terms of efficiency, emissions, costs (including energy costs), and environmental benefits. These analyses represent "top down" approaches.

Work specifically directed towards ozone includes NESCAUM's 1988 recommendation on gasoline refuelling. This source is considered by the agency to be one of the largest uncontrolled sources of ozone precursors. Stage II vapour control recovery (as defined by California, and representing existing technology) has been recommended by NESCAUM for the member states, with a target implementation date of the end of 1992. The estimated impact of this measure will be a 90% reduction of hydrocarbons emitted during refuelling.

In addition, the agency has recommended limiting the RVP of gasoline to 9.0 psi, and strongly supports a proposed federal requirement for equipping new vehicles with expanded evaporative on-board canisters to reduce gasoline refuelling emissions. It is estimated that it would take about 15 years for the latter recommendation to be fully effective, based on average vehicle turnover.
The Stationary Source Committee has recommended NO_x emission limits for combustion turbines, with various limits depending on fuel burned and size, and with some flexibility depending on levels of other emissions. Technologies available include controlling combustion, reconfiguring burners, and various post-combustion "end-of-pipe" methods, including dry and wet processes and catalytic means. Nitrogen oxides monitoring guidelines are also recommended for large projects and those where NO_x is catalytically controlled.

NESCAUM's NO_x Policy reflects the fact that about 60% of NO_x emissions in the region are from mobile sources and 40% from utilities and power generation. The four policy initiatives are:

1. Member states will require that new or modified major NO_x stationary sources perform a top down BACT analysis as discussed above and install the control technologies demonstrated to be appropriate.

2. The states have committed to evaluate other actions (presumably management measures) that will reduce NO_x emissions from existing stationary sources, fuels, and other area sources.

3. For mobile sources, the states will cooperatively evaluate the feasibility, air quality benefits,

and costs of adopting the California mobile source control program.

4. Finally, the states will continue to monitor NO_x emissions, evaluate their impact, and analyze the impacts of existing source reduction strategies. The policy is to be updated annually on the basis of this information.

5.2.5 *THE DUTCH KWS 2000 PROJECT AND OTHER EUROPEAN INITIATIVES*

With a large population, many vehicles, and a large farm animal population crowded into a very small country, the Netherlands is self-acknowledged to be one of the most polluted countries in the world. It also suffers from air-borne pollution from the many other European communities. As a result the Netherlands has taken a lead in initiating a program to control VOCs.

It has been estimated that 70-90% of the current 225 metric tons of annual VOC emission would have to be eliminated to reduce all effects on the country's population and crops. Since this figure is considered impossible to achieve with present technology, an immediate goal of an overall 50% reduction of VOCs by the year 2000 has been set in the KWS 2000 Project. The KWS 2000 Project is a national program that will be enforced through national legislation. In addition, talks are under way within the Economic Commission for Europe (ECE) of the United Nations to attempt to coordinate international VOC legislation. The ECE two years ago began work on a VOC Protocol that calls for drastic emission reductions; this protocol will be within the framework of the existing Convention on Long Range Transboundary Air Pollution (which has already seen agreements on NO_x and SO_2 emissions). Without such coordination on the transboundary nature of NO_x/VOC pollution, it is considered unlikely that major VOC reduction can be achieved. The international coordinating effort is thus a strong priority of the project.

Emissions reduction measures for vehicles (e.g., the recently adopted EC Consolidated Directive) are already in place but have not sufficiently slowed the VOC emission rate. There is the possibility that vehicle emission standards very similar to the 1990 US Clean Air Act will be introduced soon. Further effort now is being directed towards stationary sources, and to this end a reduction plan has been defined that states the percentage reduction expected from every specified source category, set in cooperation with the industries involved. For the time being, the plan focuses only on stationary sources that emit more than 100 tonnes of VOC per year, of which the most important have been tentatively identified as:

- solvent use (responsible for about 28% of VOC anthropogenic emissions in the EEC and 65% of emissions in the Netherlands);
- metal photogravure and flexogravure degreasing;
- packaging;
- motor vehicle paint;
- building paint and other paint used by the public;
- industrial painting of metallic surfaces;
- industrial painting of wooden surfaces.

A review of each of these sectors, their contribution to the VOC problem, possible technical and management measures to control emissions, and proposals for doing so is underway. In addition, provisions related to evaporative vehicle and fuel marketing emissions are being planned, and there is a three level ozone warning system in place.

Although different VOC compounds have different reactivities, it has been decided not to distinguish among them in abatement strategies. European ozone levels are also thought to be controlled by non-methane VOCs rather than NO_x or methane emissions, so most effort is being directed at the organic compounds. This situation -- and the distribution of emissions among different sources - varies significantly from the B.C. emission profile.

For each sector, the government is making money available for demonstration projects with promising new technologies. A free Bulletin Board on VOC compounds has been created to provide easy access to literature abstracts, papers, reports, symposia announcements, and so forth, as well as providing e-mail and networking services with VOC interests of all kinds.

Individual measures will include substitute products and processes, as well as additional measures such as adsorption, condensation and biofiltration limiters for specific problems. In the paint sector, for example, there has been rapid progress in the development of low-solvent and solvent free paints, but "end-of pipe" solutions may still be needed in some cases. Management measures in the traffic sector are also being considered, including siting of parking spaces and introduction of real market prices for driving and parking.

Member countries of the EC may also take additional individual measures. The UK, for example, through its new Environmental Protection Act is extending the Crown's legal ability to legislate and

control emissions to land and water from a wide range of major sources that previously may have been under only local control on a "nuisance" basis (ie, because of odour) or on the basis of emission concentrations, rather than amounts. Some smaller sources will remain under Local Authority control, but the control will now include pre-operation registration and approval of specified industrial plants contributing to VOC emissions, rather than after-the-fact control based on nuisance provisions.

Sweden has mean summer values as well as episodic ozone concentrations that exceed the guidelines for air quality. It plans a 50% reduction of its VOC levels and there is a joint action plan by the Nordic countries for a 50% VOC reduction by the year 2005, with Sweden reaching a 60% reduction by that year. The most important measures are in the traffic sector by the continuous and further use of catalytic converter systems and control of evaporative emissions in petrol stations (which must have an efficiency of 70% when operated by "normal customers"). Other measures focus on improved combustion (especially in small wood-fired stoves), increased use of district heating, application of best available technology in the industrial sector (e.g., in auto manufacturing, VOC emissions will have to decrease from 16 kg to 3 kg per car), and substitution, reformulation, and labelling in the product sector. Some firms in the package printing sector have reduced VOC emissions over the past ten years by 97% through use of new inks and printing techniques. Other work has concentrated on improving ambient VOC measurement technology: new systems used to monitor VOC levels around oil refineries, for instance, have found emission levels higher or much higher than anticipated.

5.3 Specific NO_x/VOC Management Measures

In this section, we identify management measures for specific source sectors.

5.3.1 *OVERVIEW OF TYPES OF MEASURES*

Our review of control measures proposed for these gases indicates several main categories:

1. Reduction of emissions of traditional gas and diesel vehicles through:
    - technical improvements to engine and exhaust design;
    - improvements to control of evaporative fuel emissions; and
    - improved and increased inspection and maintenance procedures.

2. Reduction of vehicle emissions through use of alternative fuels:
    - for both diesel and spark engines (e.g., methanol, natural gas, propane, etc.);
    - by novel types such as electric, hydrogen fuel cell, etc.

3. General reduction of emissions through systems management:
    - for energy systems
    - for emission systems; and
    - for traffic systems in the road transportation sector.

4. Control of evaporative and other fugitive emissions from other sources such as solvent manufacture and use, storage of volatile liquids, various industrial processes, dry cleaning, use of surface coatings, and so forth.

5. Energy efficiency and conservation measures mainly aimed at reducing energy consumed from NO_x-producing sources (e.g., coal-fired plants). Additionally, some measures are aimed at fossil-fuel burning generally, such as wood burning and homes heated by fossil fuels.

Some opportunities also exist for emission reduction through interfuel substitution of traditional fuels. Specifically, the table of emission factors in Table 6 suggests that, in the industrial sector, further switches from oil to natural gas could reduce emissions. This can be included as a general measure, although it received little individual attention in the literature reviewed. Some control measures less relevant to B.C., such as those directed towards modifications of burners in coal-fired power plants, or "end-of-pipe" clean up technologies for such sources.

This section describes the control measures of most interest in B.C. They were selected because they relate to NO_x and/or VOC, and are associated with the major classes of SCC sources identified in Table 5. Of particular interest are those measures related to the five major categories of sources identified in that section which form the basis of the sub-sections below. Other jurisdictions, however, do not necessarily use the same categories so we have described the strategy or measure in the most similar sub-section.

As may be easily seen, the amount of information available for each measure varies widely. In some cases, there is a difference between "strategies" and "measures": the former being a generic name for a series of individual measures, or possibly only a conceptual design for such measures, often with little detail; the latter comprising specific techniques for reducing pollutants and possibly

TABLE 6. Relative Emissions of NOx/VOC/N_2O by Fuel Type

Fuel Type	Emissions (Tonnes/PJ)			
	NOx	VOC	N_2O	Average (CO_2 equivalents)
Industrial				
Diesel Fuel Oil	1,100	88	0.035	44,980
Coal	250	1.5	0.2	10,075
Wood/Liquor	[110] 60	[39]	?	[4,829] > 2,400
Heavy Fuel Oil	160	2.9	0.1	6,460
Light Fuel Oil	62	0.6	[0.100]	2,515
Natural Gas	59	1.2	0.035	2,380
Road Transportation[a]				
Gasoline	359	477	-	19,600
Diesel	917	87	-	37,637

Notes

[a] 1990 Values
[ ] indicates highly uncertain estimates

Sources: Energy, Mines & Petroleum Resources (1990)

being more detailed.

For the SCAQMP, only Tier I efforts are described.

5.3.2 *ROAD TRANSPORTATION*[7]

Overview

The main categories of road transportation measures are:

1. Public/driver education: Education campaign to encourage energy conserving driving habits and alternative transportation modes (e.g., opportunities for trip consolidation, driving within the speed limit, public transit);

2. Emission standards: Tighter emission standards for both light duty and heavy duty vehicles, usually with a phase-in period and required fleet performance;

3. Inspection and maintenance programs: Regularly scheduled inspection and maintenance (I/M) to test for emissions relative to standards. Failure of the test either due to emission control tampering or outdated emission technology would require repair/maintenance prior to relicensing.

4. Measures related to gas volatility[8]: Different blending and formulations to reduce volatility (i.e., the propensity to evaporate).

5. Alternative fuels: Fuel switching to fuels or energy sources with lower NO_x/VOC emissions. A variety of alternative fuels are considered, including compressed natural gas, methanol, gasohols, LPG's, propane, variable aromatic content gasoline, reformulated gasoline, and electricity.

6. Traffic management: Traffic management encompasses a wide variety of measures related to:

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7 Also relevant to some off-road measures.

8 On-board measures only; gas volatility measures related to gas marketing are discussed briefly in Section 5.3.7.

- overall reduced traffic through various means to discourage driving and encourage alternative travel means (eg, legal controls on driving mileage, severe parking restrictions, improved public transit, employer credits for providing transit passes or car pooling coordinators, land use changes that encourage higher urban density or more mixing of commercial and residential zoning, etc.); and

- improved traffic mobility (and thus shorter travel times and emissions) through means such as expanded computerized traffic signal operations, "smart" highways that measure and re-route traffic when congested, semi-automatic vehicle navigation and control, reduced vehicle sizes, and so forth.

7. Pricing mechanisms: Pricing mechanisms are often employed as a policy tool for some other measure. For example, traffic management measures to reduce urban commuting could include elimination of parking subsidies.

More stringent fuel efficiency standards were also noted as a management measure in some documents.

Table 7 indicates the coverage of each of the categories of measures in the policy documents. As indicated, emission standards are noted by most of the studies and can lead to significant NO_x/VOC abatement. Gas volatility was also mentioned frequently, although it is not entirely clear that these measures should be considered as vehicle-specific measures or as those related to gas marketing. Traffic management was frequently noted, usually as a package of individual measures considered in combination.

Although alternative fuels are frequently mentioned -- and play an important role in the U.S. policies -- there is still considerable uncertainty concerning their environmental performance. A brief review of the literature (see Appendix H) indicates conflicting conclusions. Although many of the studies reviewed showed a decrease in VOC emissions, NO_x emissions could be higher or lower in gasoline engines. Combined, it is not possible to definitively conclude that alternative fuels will consistently provide benefits in the management of NO_x/VOC emissions.

TABLE 7. Coverage of Road Transportation Measures

Policy Document	Measure						
	Public Education	Emission Standards	Inspection & Maintenance	Gas Volatility	Alternative Fuels	Traffic Management	Pricing Mechanisms
1. CCME	*	✓	✓	✓		*	
2. SCAQMP		✓			✓	*	*
3. USCAA		✓	✓	✓	✓	✓	
4. NESCAUM				*			
5. Europe		✓		✓		✓	
6. GVRD Air Mgmnt. Plan		✓	✓	✓	✓	*	✓
7. Vancouver City						*	✓
8. Ontario sector study		✓	✓	✓	✓	*	✓
9. Other[a]	*	✓	✓	[b]	*	*	

Notes

* More than one measure
[a] Includes GVRD I/M Program, Vancouver Oxidant Study and GVRD Fleet Emission Study.
[b] Gas marketing and distribution measures only.

Data on Various Management Measures

As noted above, data on various management measures with respect to abatement potential, cost-effectiveness, and information on barriers to implementation are not readily available in the literature. In some policy documents, potential abatement is measured, but costs are ignored; in other studies, costs and abatement potential are highly aggregated into "bundles" of measures and, therefore, preclude a measure-by-measure comparison[9].

CCME NOx/VOC Management Plan: The CCME Management Plan[10] does provide some cost and abatement potential (for the Lower Fraser Valley for the year 2005). This information is summarized in Table 8. As indicated, the measures vary considerably in their abatement potential, cost and extent of barriers to implementation. The most promising measures from an abatement perspective are new vehicle emission standards for light duty vehicles which, the CCME Management Plan estimates, could reduce emissions in the Lower Fraser Valley by about 40 kt CO_2 equivalent in the year 2005. (Similar standards for heavy duty vehicles could reduce emissions by about 9 kt CO_2 equivalent in 2005.)

Standards have an additional benefit of moderate to low barriers to implementation. The technical barriers to emission reductions in new cars will be the responsibility of the car manufacturer, in many cases driven by similar U.S. legislation. However, implementation could be more difficult for older cars as the technology for emission retrofits is not readily available. Inspection and maintenance programs and gas volatility also show potential to reduce NO_x/VOC emissions (40-50 kt CO_2 equivalent per year). The costs for gas volatility measures are relatively low (about $125 per tonne CO_2 equivalent) with low barriers to implementation. According to the CCME report, the cost of inspection & maintenance is high (over $800 per tonne CO2 equivalent) which could moderate the attractiveness of this measure.

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9 Abatement and cost-effectiveness for specific road transportation measures have been calculated for carbon dioxide management for the B.C. context in a companion study for B.C.Ministry of Environment (see The ARA Consulting Group Inc. Evaluation of Carbon Dioxide Management Measures for B.C.) The ranking of management measures for CO_2 would correspond roughly to the rankings for NO_x/VOC emissions because both are based on energy use. (Note: The results of the CO_2 study had not been finalised at the time of writing.

10 CCME measures related to transportation do not always discriminate among road, off-road, and gas/diesel modes. All measures beginning with prefix N are NO_x measures; all those beginning with V are VOC measures.

TABLE 8. Plan and SCAQMP Road Transportation Measures: CCME Management Plan

Measure/Strategy[a]	Abatement[b]	Costs[c]	Barriers
Panel (A) CCME Management Plan			
Public Education (N201; V201)	NE	NE	High
Highway Education (N503)	NE	NE	Moderate
Highway Enforcement (N502)	Low	Low	Low
Vehicle Standards (N301; V301 Light Duty Vehicles)	High	Moderate	Low/Mod
Vehicle Standards (N302; Heavy Duty Vehicles)	Low	NE	Low
Inspection & Maintenance Program (N601; V601)	High	High[d]	Low
Gas Volatility (Vehicle Only; V602)	High	Low	Low
Urban Transportation Management (N401; V401)			
a) Incremental Approach	NE	Low	Moderate
b) Proactive Approach	NE	Moderate	High
Panel (B) South Coast Air Quality Management Plan			
Technical Measures	High	NE	Varies
Traffic Management Measures	High	Varies	High

Notes

NE No Estimate

a See Appendix H for detailed definitions.

b Low = < 15 kt per year
Moderate = 15 - 30 kt per year
High = > 30 kt per year

c Low = < $300 per tonne
Moderate = $300 - $700 per tonne
High = > $700 per tonne

d Excludes cost savings from fuel efficiency improvements.

Although the CCME plan does not provide estimates of abatement potential, other documents suggest that reductions from urban transportation management measures could be significant. Their costs will depend on the time frame chosen to implement different measures. For example, if an incremental approach is adopted (i.e., changes are made gradually in the normal course of city planning) costs could be low; however, if changes are to be introduced over a short time frame, costs would rise.

Considerable implementation barriers can be expected for urban transportation management measures related to political controversy, inconvenience, lack of independence and flexibility. As noted in the CCME Plan, this measure -- if actively implemented -- will have considerable impact on people's lifestyles and consumer choice. For the same reasons, public education efforts will face barriers to implementation or, more precisely, to successful implementation.

Another promising measure is an inspection and maintenance program. Generating moderate levels of emission reductions, the barriers to implementation are not expected to be significant if supported by regulatory measures. CCME estimates costs at about $350 per tonne reduced, although other studies (e.g., SCAQMP) suggests much lower costs.

South Coast Air Quality Management Plan: The SCAQMP's general vehicle approach is divided into two main strategies: (i) to severely limit future NO_x and VOC emissions through technical measures; and (ii) to reduce emissions through traffic management measures. Abatement potential is estimated for the two strategies, but costs are available for only some of the individual measures included in each strategy.

The technical strategy includes:

- standards that will require additional reductions in VOC and NO_x of 50% and 80% respectively relative to current standards;
- requiring the sale of zero emission vehicles beginning in 1988;
- allowing use of alternative fuel vehicles; and
- requiring widespread availability of alternative fuels[11].

The traffic management measure seeks to reduce road vehicle emissions through 24 individual transportation and land use measures related to:

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11 The SCAQMP treats vehicles and fuels as a system in order to attain emission standards by allowing more flexibility and cooperation between manufacturers and fuel suppliers.

- reduction of vehicle miles travelled;
- facility improvements;
- growth management;
- congestion relief; and
- mode shift.

Specific measures include market incentives, local and regional ordinances and regulations, reductions to person-work-trips, parking management, transit improvements, truck dispatching and rescheduling, user fees, auto buybacks, alternative work weeks and flextime, telecommuting, non-motorized transportation, vanpool purchase incentives, employer rideshare and transit incentives, etc. The traffic management measure closely resembles the CCME's urban transportation management measure.

Abatement potential for the technical and traffic management strategies were estimated at about 1000 and 600 kt CO_2 equivalent per year, respectively for the South Coast area[12]. Costs for some specific measures (e.g., school trips, fleet turnover) were calculated; however, these estimates are of only limited use in this study as they are expressed in terms of cost per tonne of all pollutants reduced, not just NO_x and VOC. Given the focus of this study, these "macro" cost-effectiveness estimates cannot be used to rank NO_x/VOC measures.

Ontario Transportation Sector Study [13] The Ontario study examined eight separate energy saving actions for the transportation sector. Each measure is characterized by energy saving potential and applicability. Actions are then "bundled" to satisfy a number of scenarios for carbon dioxide emissions. Furthermore, the study specifies the method of implementation, which is referred to as a "strategy". Strategies include either economic measures or regulatory measures, or some combination of the two. Energy savings and emission reductions are estimated for each of the twelve scenario/strategy combinations. These strategies are not yet policy in Ontario.

For the first scenario -- actions economically attractive to society (without significant lifestyle

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12 Prorating these emissions based on population suggests reductions in the order of 650 kt and 110 kt CO_2 equivalents per year for technical and traffic management, respectively.

13 VHB Research and Consulting Inc. et. al. (1991), *Reduction in Energy Use and Emissions in Ontario's Transportation Sector*. Prepared for the Ontario ministries of Energy, Environment and Transportation; Toronto.

changes) -- the study concluded that the following actions would yield the largest reduction in NO_x/VOC emissions:

- subsidies and incentives for public transit leading to a moderate increase of the transit share of urban transportation to 13 percent for the province and a 5 percent reduction in urban travel demand;

- incentives for the use of communications rather than transportation resulting in a 5 percent decrease in urban and inter-city travel demand;

- new Canadian Automobile Fuel Efficiency (CAFE) standards for private motor vehicles and trucks resulting in a 20 percent reduction in passenger vehicle fuel consumption and 10 percent reduction in truck fuel consumption by 2005;

- urban traffic management measures resulting in a 5 percent reduction in urban private and public vehicle fuel consumption; and

- regular inspection and maintenance of passenger vehicles resulting in a 5 percent reduction in fuel consumption.

Implemented through a combination of regulatory and economic measures, the study estimates a 1% increase in energy use in the sector by 2005 compared with 1988 base. (The base case forecast in the absence of any management measures suggests a 29% increase in energy demand over the same period.) The corresponding decrease in NO_x and VOC emissions is 35% and 44%, respectively (compared to 32% decrease in the absence of any management measures).

The actions combined to meet the second scenario -- to stabilize CO_2 emissions at 1988 levels by 2000 -- are essentially the same as those for the first scenario, with virtually identical impacts on NO_x/VOC emissions.

The third fourth scenarios include actions that are costly (i.e., not economically attractive to society) or that may require significant lifestyle changes. Actions included in the third scenario -- a twenty percent reduction in 1988 carbon dioxide emissions by 2005 at least cost -- are:

- new CAFE standards for private motor vehicles and trucks resulting in a 32 percent reduction in passenger vehicle fuel consumption and 14 percent reduction in truck fuel consumption by 2000;

- urban land use management measures resulting in a 10 percent reduction in urban travel demand;

- urban traffic management measures resulting in a 5 percent reduction in urban private and public vehicle fuel consumption;

- regular inspection and maintenance of passenger vehicles resulting in a 5 percent reduction in fuel consumption; and

- restrictions on passenger vehicle travel resulting in a 30 percent reduction in passenger vehicle travel.

Implemented through regulatory means, these measures could reduce energy demand by 28% over base case 1988 levels, with NO_x and VOC reductions of 43% and 57%, respectively.

The final scenario meets a 20% reduction in CO_2 emissions by 2000 but also sets the stage for further reductions in the future. The combination of actions differs from the previous scenario as does the strategy (a combination of regulatory and economic measures). The actions are:

- subsidies and incentives for public transit leading to a 22 percent transit mode share for the province and a 14 percent reduction in urban travel demand;

- incentives for the use of communications rather than transportation resulting in a 10 percent decrease in urban and inter-city travel demand;

- new CAFE standards for private motor vehicles and trucks resulting in a 32 percent reduction in passenger vehicle fuel consumption and 14 percent reduction in truck fuel consumption by 2000;

- urban land use management measures resulting in a 15 percent reduction in urban travel demand;

- urban traffic management measures resulting in a 10 percent reduction in urban private and public vehicle fuel consumption;

- regular inspection and maintenance of passenger vehicles resulting in a 5 percent reduction in fuel consumption; and

- restrictions of passenger vehicle travel resulting in a 20 percent reduction in passenger vehicle travel.

The study estimates that these measures could reduce energy demand by 24% (over 1988 levels), with concomitant decreases in NO_x and VOC emissions of 43% and 58%.

The three scenarios are summarized in Table 9. As indicated, fuel efficiency standards (i.e., CAFE standards) play an important role in initial reductions in NOx/VOC emissions in the transportation sector. At moderate levels, changes to standards can be economically attractive. Similarly, an inspection and maintenance program and moderate levels of modal shifts to transit, increased use of communications rather than transport, and traffic management measures are economically attractive.

High levels of emission reduction (i.e., 43%/58% vs. 35%/44% for NOx/VOC) depend on land use measures and regulatory restrictions on passenger vehicle travel. These actions could be costly and are likely to impose significant lifestyle changes. If introduced over a relatively short time frame, these measures are likely to be difficult to implement. In addition, larger reductions in emissions could require stronger transit and communications actions that, unlike moderate levels in the first scenario, incur costs.

Summary -- Road Transportation: The management plans for air quality and NO_x/VOC specificallydevote considerable attention to measures for the road transportation sector. Although various policy documents define measures differently, several measures tend to dominate. Table 10 summarizes these measures by abatement potential, cost and barriers to implementation.

As indicated, there is some gradation in the attractiveness of measures. However, three measures stand out: gas volatility measures; vehicle fuel efficiency standards; and inspection and maintenance programs. All three measures could yield high or moderate-high emission reductions, yet all are

TABLE 9. Road Transportation Measures: Ontario Transportation Study

Action	Scenario I	Scenario III	Scenario IV
Increase Share of Public Transit	Moderate		Strong
Increase use of Communications	Moderate		Strong
New CAFE Standards	Moderate	Strong	Strong
Urban Traffic Management Measures	Moderate	Moderate	Strong
Inspection & Maintenance Program	Moderate	Moderate	Moderate
Land Use Measures		Moderate	Strong
Restriction on Passenger Vehicle Travel		Severe	Strong

Notes

Scenario I: Actions that are economically attractive to society (with no signifigicant lifestyle changes).

Scenario III: 20% reduction in CO2 emissions at least cost.

Scenario IV: 20% reduction in CO2 emissions, best position for future reductions.

Source: Based on VHB Research & Consulting (1991)

TABLE 10. Summary of Road Transportation Measures

Measures	Abatement	Costs	Barriers
Gas Volatility	High	Low	Low
Vehicle Fuel Efficiency	High	Low/Moderate (a)	Low/Moderate
Inspection & Maintenance Program (a)	Moderate/High	Low	Low
Restrictions on Demand	High	Moderate	High
Land Use Measures	High	Moderate/High	Moderate/High
Communications (a)	Moderate	Low	Low/Moderate
Increased Transit Use (a)	Moderate	Low	Moderate
Traffic Management Measures (a)	Moderate	Low	Moderate
Alternate Fuels	?	Moderate	Moderate/High
Public Education	?	?	High

Notes

a. At moderate levels of implementation.

relatively low cost and have low or low-moderate barriers to implementation.

Beyond these measures, trade-offs between cost/barriers and abatement potential become more pronounced. For example, restrictions on passenger vehicle travel could significantly reduce emissions, but at some cost and considerable inconvenience and lifestyle changes. By contrast, more modest reductions could be gained through traffic management measures, increased use of transit and increased use of communications in place of travel.

At this time, alternative fuels are not included in the set of promising measures because of high barriers to implementation (i.e., the feasibility of alternative fuels, lack of infrastructure for refuelling, range and convenience issues) combined with moderate costs and, most importantly, uncertainty over their potential contribution to emissions reduction.

A range of policy tools are available to implement transportation measures. Apart from regulatory mechanisms, variety of market incentives could be used. The SCAQMP discusses several market incentives for transportation management[14]. Concepts under review include:

- expanding the existing Emission Fee System;
- use of emission reduction credits and offsets for indirect sources;
- employee benefit incentives for parking management;
- toll roads, congestion fees to increase vehicle occupancy and promote other travel modes;
- emission fees for higher pollution engines to promote turnover;
- market incentives to address regional growth imbalances;
- "trading market" for stationary sources to demonstrate annual emission reductions;
- tax credits to lower cost of pollution control equipment;
- small business loans;
- increased licence fees for older vehicles;
- consumer labelling and surcharge pricing for high-VOC products; to find public education.

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[14] Market incentives are being considered in the management of NO_x/VOC/N_2O and general air quality in a number of jurisdictions because they can, in some instances, reduce the costs of air quality improvements. Part of the cost savings is generated by lower monitoring and enforcement costs and part by increased flexibility among polluters that encourages lower cost polluters to cut back emissions more than an industry average embedded in a regulatory framework. Market incentives do, however, still require considerable policy analysis to determine the most appropriate mechanisms and levels of emission reductions, and to assess distributional and trade consequences.

5.3.3 *SLASH BURNING*

Slash burning, a by-product of the forestry industry, accounts for approximately 9% of total NO_x/VOC/N_2O emissions in the Province. Slash burning is carried out to prepare sites for planting and to increase survival rates of seedlings. Alternatives to slash burning include mechanical treatment, herbicide application, no site preparation (with more time and money spent on planting larger seedlings), "clipping treatments", various versions of each of these methods, as well as various combinations.

Since 1987, the Ministry of Forests has required a "prehazard silviculture prescription" for each area prior to logging. This prescription classifies the site ecologically and examines the most appropriate sequence of management measures, including an initial recommendation on the appropriate method of site preparation. These prescriptions are available for public scrutiny. After logging, a site preparation plan is developed that confirms/rejects/modifies the recommendations in the silviculture prescription (Forestry Canada, pers.comm.).

The choice of site preparation method depends on a variety of factors, including the topographical characteristics of the site (e.g., slope, slope stability), climate/weather conditions, nature of the harvest residue and soils, type of competing vegetation, pest control issues, costs of planting/burning/etc., to name a few. The relative importance of each factor will vary over time and for each site.

A simplistic response to managing emissions from slash burning is to encourage or force alternative methods of site preparation. The states of Washington and Oregon have in place restrictions on slash burning, but these are driven by a concern over smoke and particulate emissions (and the associated visibility, aesthetic and health implications) rather than NO_x/VOC/N_2O emissions. These restrictions are wholly dependent on weather conditions, such as wind speed and direction, temperature inversions, etc.[15]

Increased restrictions on slash burning have been accepted by industry as an inconvenience, but research on alternatives has been accelerated. In Oregon, alternatives include different methods of burning, utilization of harvest residues, mechanical treatment, and no preparation. The lesson from experiences in the Pacific Northwest of the United States is that slash burning is not a critical

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15 Slash burning in Washington and Oregon has not received much attention within the global warming context.

element in forest management; however, the same foresters will defend slash burning (and fire in general) as a necessary and integral part of the natural cycle of the forest ecosystem.

In B.C., there is recognition among government and research foresters that the appropriate method of site preparation -- even from a strictly ecological perspective -- is highly site dependent. Thus, a strong push to reduce or even ban slash burning for NO_x/VOC/N_2O reasons may compromise other goals, including the rate and success of regeneration, and hence, encounter significant cost and barriers to implementation.

In conclusion, then, we suggest that efforts to reduce slash burning should be pursued, but that a blanket policy restricting the practice could compromise other objectives of forest management and environmental quality. A more appropriate recommendation would be to expand site by site analyses and "prescriptions" so that the decision to burn is conscious and well thought out, not an automatic solution to a traditional problem.

5.3.4 *TRANSMISSION LINES*

The inventory identifies transmission lines as a possible source of N_2O. In this section we outline some of the management aspects associated with this source. However, the section is very brief because of the uncertainty of the inventory numbers. To recap, the inventory numbers are based on a single article and have yet to be substantiated by other empirical evidence. Clearly, further investigation is required before management measures can be seriously addressed.

Having said that, minimizing N_2O by minimizing corona loss is in the best interest of the transmission utility as corona loss equates to power loss and, hence, revenue loss. Cost-minimizing incentives that are currently in place, therefore, encourage implementation of corona loss measures, at least within the context of overall system planning.

Corona loss can be reduced by design features, in particular, the choice of conductor, pre-installation care of the conductor and general "clean" construction of transmission lines. Although corona loss is generally higher on low voltage lines, locating power sources closer to demand centres may reduce overall corona loss by reducing the amount and distance power must be transmitted.

A more in-depth examination of corona loss measures is warranted only after further study

confirms its role in the total NO_x/VOC/N_2O inventory.

5.3.6 *OFF-ROAD TRANSPORTATION*

Off-road management measures will, to a certain extent, coincide with the measures/strategies noted above. However, the CCME Plan does note one measure (new standards for NO_x emissions, N303), related to construction vehicles. The expected reduction in NO_x from this measure is estimated at about 15 kt CO_2 equivalent in the Lower Fraser Valley in the year 2005 (compared with 190 kt for light duty vehicle emissions).

The SCAQMP strategy for off-road emissions consists of more stringent emission standards and operational modifications for a variety of engines, including construction and farm equipment, off-road motorcycles and vehicles. However, the strategy also includes initiatives for rail, air and marine vehicles, thereby restricting the extent to which conclusions on abatement potential, cost, etc. can be applied to B.C. with any degree of confidence.

5.3.5 *PULPING (KRAFT PULP)*

Kraft pulping accounts for about 3% of NO_x/VOC/N_2O emissions in the province, mainly from NO_x emissions from recovery boilers. Its role is not surprising; pulp and paper is a major industry in the province and is a significant energy user. Furthermore, the kraft pulping process -- the source of most of the emissions in the inventory for this sector -- generates and burns high volumes of wood waste and pulping (black) liquor, both of which have high NO_x emission factors.

Simplistically, one management measure would be to substitute natural gas as an energy source, with appropriate boiler controls and conservation measures. However, these waste products are generated as an inherent part of the kraft pulping process and, if not used for energy in the recovery boiler, would have to be incinerated as a waste product. Incineration would generate similar amounts of NO_x, possibly increasing total emissions (when natural gas emissions are taken into account).

In order to reduce emissions, then, measures should focus on:

- finding alternative uses for the wastes that keep the NO_x/N_2O "locked in" (i.e., do not

entail burning);

- reducing the amount of wood waste and liquor generated; or
- reducing NO_x emissions using controls and new source standards for boilers.

While there may be some opportunities for uses of wood wastes, we are not aware of viable alternatives for black liquor.

Reducing the amount of waste generated could require significant changes in process. For example, thermo-mechanical pulping (TMP) uses a much higher percentage of the wood fibre, essentially eliminating black liquor waste[16]. However, TMP produces a very different grade of paper product which may have implications for industrial competitiveness. Another possible process change would be towards greater use of waste paper as a raw material. In addition to significantly lower energy requirements, recycled paper avoids much of the waste issue. Clearly, any process changes will be long-term measures, implemented over a considerable time frame and modified by both short and long-term demand and market considerations.

The third option for reducing NO_x and N_2O emissions -- controls on boilers -- may be possible, although the general literature reviewed for this study did not discuss pulping processes specifically. The CCME Management Plan does include a number of measures related to new source performance standards for commercial/industrial/power plant boilers (N305, N306, N602, N603) but the applications of these standards to kraft pulping liquors were not addressed. This is an area for further investigation.

Note: The CCME Management Plan identifies NSPS and retrofit standards for VOC emissions from pulp and paper. However, according to the B.C. inventory, VOC emissions from the pulp and paper sector are insignificant.

5.3.7 *OTHER SOURCES*

Rail Transportation

The only measure specific to rail transportation was found in the CCME Plan (CCME N304). This measure calls for a cap on NO_x emissions from Canadian rail transport systems at 115 kt per year nationally (800 kt CO_2 equivalents per year) effective in 1992 through:

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16 TMP is electricity-intensive, generally purchased from the main BC Hydro grid.

- replacement of locomotive fleets with engines with lower emission rates;
- railway system improvements; and
- reporting system to accompany new standards.

The cap represents a decrease in national emissions of about 115 kt CO_2 equivalent by the year 2005. No regional breakdowns were given.

Some California measures involve railways. However, these are generally subsumed under the off-road transportation sector and could not be separated out.

Solvents and Surface Coatings

The literature identifies a number of measures specifically related to solvent use and surface coatings, including numerous measures in the CCME Plan. Estimated abatement potential and cost-effectiveness are presented in Table 11.

Several measures are expected to be costless (i.e., cost-effectiveness equals zero suggesting neither costs nor savings), although some measures are expensive (up to $1200 per tonne in the CCME Plan and up to $28,000 per tonne in the SCAQMP). Expected emission reductions are greater for surface coatings than solvent use, amounting to about 70 kt in the Lower Fraser Valley in the year 2005 (including higher cost retrofits and NSPS). This figure compares to the potential reduction in emissions from a vehicle inspection and maintenance program of 75 kt.

The SCAQMP combines solvent and surface coating measures into area and point source categories. As indicated in Panel c of Table 11, area source measures dominate both from cost and abatement perspectives.

Gas and Diesel Marketing

Panel d in Table 11 lists gas and diesel marketing measures from the CCME Management Plan, the SCAQMP, and the Vancouver Oxidants Study (BH Levelton, 1989). As indicated, some measures are cost-effective; specifically, BH Levelton estimates that modifications to fixed roof tanks could conserve energy thereby generating cost savings[17]. In the SCAQMP, the closest measure/strategy to the CCME's set was "petroleum and gas production" that includes various vapour balancing and

17 Depending on size, emissions from fixed roof tanks can be reduced by (i) adding floating decks, (ii) vapour balancing during filling, and (iii) installing secondary seals.

TABLE 11. Other Management Measures

Panel a) Solvent Use

Measure	Source	Abatement[a] (kt CO_2 equivalents per year)	Cost - Effectiveness (1989 $ per tonne CO_2 equiv.)
❑ Adhesive emissions lower by 40%	CCME V102	8	zero
❑ Misc. industrial solvents lower by 20%	CCME V104	5	zero
❑ Public education re: solvents	CCME V201	NE	NE
❑ Industrial degreasing standards	CCME V309 & V614	8	100-200
❑ Dry cleaning standards	CCME V310 & V615	4	900-1,200

Panel b) Surface Coatings

Measure	Source	Abatement	Cost-Effectiveness
❑ Consumer surface coatings lower by 20%	CCME V101	8	zero
❑ Industrial surface coating standards	CCME V307 & V612	62	NE

Panel c) Combined Solvents & Surface Coatings

Measure	Source	Abatement	Cost-Effectiveness[d]
❑ Point sources[b]	SCAQMP	12	3,300 - 28,000
❑ Area sources[c]	SCAQMP	26	330

Panel d) Gas & Diesel Marketing

Measure	Source	Abatement	Cost-Effectiveness
❑ Vapour balancing & recovery at gas storage & transfer depots	CCME V603	4	100
❑ Vapour balancing & recovery at service stations	CCME V604	15	200
❑ Vapour balancing & recovery during fuelling	CCME V605	22	3,000
❑ Vancouver Oxidants Study: bundle of measures	BH Levelton, 1989	43	-110 to 4,000 average: 190[e]
❑ Petroleum & gas production[f]	SCAQMP	10	140-1,300

Notes:
NE: No estimates

a: Estimated for Lower Fraser Valley

b: Includes reformulation, higher transfer efficiency, process improvements, add-on controls, alternative coating methods & solvents

c: Includes reformulation, emission charges, process improvements, alternative application methods & solvent waste minimization.

d: Approximate cost per tonne of all pollutants reduced.

e: Excluding refueling modifications that average $4,000/tonne reduced.

f: Includes Phase I, II & improved vapour recovery systems, utility engine refuelling operations, improved fuel shut-off mechanisms.

refuelling measures. However, it is not clear that these measures are in fact comparable, a reservation that is underscored by the considerable difference in abatement potential.

5.4 Summary

One of the objectives of this study was to identify and evaluate possible measures to manage NO_x/VOC/N_2O emissions in the Province. This study builds on NO_x/VOC and general air quality plans in other jurisdictions. The Canadian Council of Ministers of the Environment's (CCME) *NO_x/VOC Management Plan* in particular provides a fairly comprehensive view of management options for NO_x and VOC. The *South Coast Air Quality Management Plan* sets out fairly stringent targets and associated measures, although the analysis of measures does not provide adequate detail on specific measures to rigorously assess them in the B.C. context (e.g., the measures are aggregated and take into account impacts on all pollutants, not just NO_x/VOC).

The review of management measures focused on the main sources of NO_x/VOC/N_2O in the Province: i.e., road transportation, off-road transportation, transmission lines, slash burning, and kraft pulping. As the largest source, road transportation received the most thorough review, although important options in other sectors were identified. A long list of measures is presented in Table 12.

The most promising management measures[18] lie in the road transportation sector (see Panel a in Table 12). Among the 12 options, the most promising road transportation measures are:

- reduced gas volatility;
- vehicle fuel efficiency standards; and
- inspection and maintenance program.

Each of these three measures have the potential to reduce emissions by more than 30 tonnes of CO_2 equivalent emissions annually and have low or low/moderate costs and barriers to implementation. Furthermore, all could be implemented in the short to medium term. Collectively, these measures could reduce NO_x/VOC emissions by about 225 kt CO_2 equivalent per year, or about 3% of total

18 "Most promising measures" are defined as those measures that yield high emission reductions at low cost and low barriers to implementation, relative to other measures.

Table 12: Summary of NO_x/VOC/N_2O Management Measures

	Abatement Potential	Cost	Barriers to Implementation
Panel a) Road Transportation			
Gas volatility	H	L	L
Vehicle fuel efficiency	H	L/M[a]	L/M
Inspection & maintenance program	M/H	L	L
Restrictions on demand	H	M	H
Land use measures	H	L	L
Communications[a]	M	L	L/M
Increased transit use[a]	M	L	M
Traffic management[a]	M	L	M
Alternate fuels	NE	M	M/H
Public education	NE	NE	H
Panel b) Other Major Sources			
New standards for construction vehicles	L	NE	NE
Site analysis (slash burning)	NE	M	M
Design features (transmission lines)	NE	L	L
Process changes (kraft pulping)	H	H	H
New boiler standards (kraft pulping)	NE	L	NE
National NOx cap (rail transportation)	M[b]	NE	L/M
Panel c) Other Sources			
Reduced solvent use	L	L	
Public education re: solvents	NE	NE	
Industrial degreasing standards	L	L	
Dry cleaning standards	L	H	
Lower consumer surface coating	L	L	
Industrial surface coating standards	H	NE	
Vapour balancing & recovery A[c]	M	L	
Vapour balancing & recovery B[d]	M	H	
Petroleum & gas production	L	L/H	

Notes:

a At moderate levels of implementation

b National emissions reduction

c At gas storage & transfer depots and service stations

d During fuelling

Definitions:	Abatement	Cost
L = Low	<15kt CO_2 per year	< $300 per tonne
M = Moderate	15-30kt CO_2 per year	$300 - $700 per tonne
H = High	>30kt CO_2 per year	>$700 per tonne

provincial emissions of NO_x/VOC/N_2O with costs below $300 per tonne CO_2 equivalent emissions reduced.

Other transportation measures raise trade-offs between abatement potential and costs or barriers. For example, restrictions on passenger vehicle transportation could reduce emissions considerably, but the implicit change in lifestyles suggests the barriers to implementation could be significant. By contrast, moderate increased share of transit, traffic management and increased use of communications in place of transportation would be relatively easy to implement (both in terms of cost and barriers), but their contributions to abatement would be more modest.[19]

Alternative transportation fuels have received considerable attention in the literature. However, based on the review conducted for this study, the net effect on NO_x/VOC emissions is inconclusive; generally, VOC emissions appear to be lower for alternative fuels but NO_x emissions could be either higher or lower. The net effect is too unclear to recommend fuel switching as a management measure.

Management options are less obvious for the three non-transportation sources (see Panel b) in Table 12):

- Restrictions on the amount of slash burning either through regulations, a special permitting process, or tax/fee incentives could reduce emissions. Alternatives to slash burning do exist, although their appropriateness and cost will vary site-by-site.

- The kraft pulping industry generates NO_x/VOC emissions in its use of waste wood and black liquor, a by-product of the kraft system. Possible management measures include encouragement of alternative production processes (e.g., recycled paper, TMP) and/or NO_x controls on burners. The attractiveness of alternative processes will depend on market factors and capital cost considerations. In the case of NO_x controls, further investigation of the technical constraints and opportunities is required.

- Although this inventory identifies transmission lines as a possible source of N_2O in the Province, the review of management measures was cursory, in line with the

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19 As noted earlier, another study funded under the Greenhouse Gases Project is developing detailed estimates of cost-effectiveness and *carbon dioxide* abatement potential for all relevant road transportation measures. The results of that study had not been finalised at the time of writing.

preliminary nature of the emissions estimate.[20] N_2O emissions can be reduced by minimizing corona loss around transmission lines. Because corona loss equates to power loss and revenue loss, it is in the electric utility's best interest to minimize corona loss. The main avenues for reducing corona loss are through design features, in particular, the choice of conductor, pre-installation care of the conductor and general "clean" construction of transmission lines.

Other management measures related to solvents, surface coatings and gas & diesel marketing are available (see Panel c of Table 12). A number of these are relatively low cost (i.e., less than $300 per tonne CO_2 equivalent) which, collectively, could reduce provincial emissions by approximately 110 kt per year, or less than 2% of the provincial total. (Note: This total excludes industrial surface coatings and public education concerning solvent use for which cost and/or abatement estimates are not available).

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[20] As noted above, emissions of N_2O from transmission lines were estimated based on a single journal article. These estimates have not been verified by local empirical evidence.

6.0 DISCUSSION AND CONCLUSIONS

6.1 Inventory Results

When the results of the inventory are expressed in terms of carbon dioxide equivalents, using the Global Warming Potentials given in IPCC (1990), the total anthropogenic emissions of NO_x, N_2O and VOCs in B.C. are a minor fraction of the total provincial CO_2 emissions estimate. The total anthropogenic emissions of the gases inventoried for this project are about 7,300 kt/y (1985). NO_x, N_2O and VOCs make comparable contributions, and Transportation is the major contributor to these emissions (50%). These numbers are to be compared with CO_2 emissions for B.C. of 84,000 kt (1988). That is, the anthropogenic NO_x/VOC/O_3 emissions as greenhouse gases are equivalent to about 9% of the CO_2 emissions in the province.

If the use of the IPCC Global Warming Potential factors is reliable (which has not been assessed), it appears that the gases inventoried for this project play a minor role as greenhouse gases. Discussions with some of the scientists who were responsible for including the indirect effects of gases such as NO_x and VOCs in the IPCC report (C. Johnson and R. Derwent, private communications, 1991) have indicated that the large uncertainties in the use of GWPs to estimate indirect effects will probably lead to their being dropped from consideration until such time as the models and data improve.

The global importance of CO_2 (estimated 61% of warming potential over 100 years) is about ten times that of NO_x, N_2O and VOCs combined (about 6% of warming potential over 100 years), according to the IPCC report (IPCC, 1990, Table 2.9, modified per private communications with Johnson and Derwent). The data reported here imply that CO_2 is also about ten times as important as NO_x/N_2O/VOC/O_3 in B.C.

While the role of NO_x/VOC/O_3 as greenhouse gases is clearly much less than that of CO_2 itself, the importance of this issue to the development of the overall management strategy for anthropogenic emissions suggests that the validity of this approach based on Global Warming Potential be reviewed. The scientific basis for the Global Warming Potential concepts proposed by IPCC is not well documented in their report.

The general consistency of the ozone emission quantity derived using both the IPCC approach and

an alternate method of estimation with existing air quality data supports the validity of the approach.

6.2 Management Measures

The review of management measures was based on NO_x/VOC and general air quality plans in other jurisdictions.[21] The review of management measures focused on the largest source sectors for NO_x/VOC/N_2O: road transportation; off-road transportation; transmission lines; slash burning; kraft pulping. These five sources account for about 70% of total emissions in the Province.

Because road transportation accounts for about 41% of provincial emissions, many of the most important management measures lie in this sector. For example, increased fuel efficiency standards, inspection and maintenance programs, and reduced gasoline volatility are the most promising measures identified in this review. All three have the potential to reduce emissions by more than 30 kt CO_2 equivalent annually, at relatively low cost and with few barriers to implementation. Collectively, these three measures could reduce emissions by about 225 kt per year (based on estimates for the Lower Fraser Valley). Other road transportation measures raise trade-offs between abatement potential and cost/barriers to implementation (including lifestyle changes).

Alternative transportation fuels have received considerable attention in the literature. However, based on the review conducted for this study, the overall effect on NO_x/VOC emissions is inconclusive; generally, VOC emissions appear to be lower for alternative fuels but NO_x emissions could be either higher or lower. The net effect is too unclear to recommend fuel switching as a management measure.

There is considerably more uncertainty surrounding management measures in other sectors. For example, a blanket policy to restrict slash burning is inappropriate given the variability of site characteristics in the Province; rather promotion of site-by-site analyses *with emissions reduction explicitly taken into account* in silviculture prescriptions is suggested. Apart from new NO_x standards for industrial boilers, emissions reductions in kraft pulping may require significant process changes that could also have serious implications for markets and competitiveness.

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21 Detailed estimates of abatement potential and costs for B.C. was beyond the scope of this study. However, a concomitant study within the Greenhouse Gases Project has developed detailed estimates of road transportation measures from the perspective of CO_2 abatement.

Further empirical work concerning the magnitude of N_2O emissions from transmission lines is called for, although cost and revenue concerns create incentives to reduce corona and line losses and, hence, N_2O emissions.

Additional emission reductions could be achieved through a variety of measures related to solvents, surface coatings and gas & diesel marketing, although some of these options are costly.

For those road transportation and other measures for which estimates were available, total abatement potential amounts to some 635 tonnes CO_2 equivalent per year, or less than 10% of total anthropogenic emissions in the Province.

As noted in the introduction to chapter 5, the list of possible management measures does not constitute a management strategy. In determining a strategy, NO_x/VOC measures must be considered within the context of other pollutants of concern. In some instances, there may be complementarity between measures, but in other cases, conflicts may arise. In some instances, cost-effectiveness may favour some measures over others. Another important aspect of a management strategy is to select the most appropriate policy tool or tools to implement the selected set of measures. These tasks will be part of the integration of all four components of the Greenhouse Gases Project.

6.3 Conclusions

There are several main conclusions to be drawn from the above discussion.

- The estimated contribution of the N_2O and O_3 documented in this inventory to the overall greenhouse gas emissions from sources in B.C. is a small fraction of the CO_2 emissions.

- NO_x and VOCs have about the same indirect global warming potential, apparently, so that the strategy for their control for other reasons, such as to reduce ground level ozone formation, is not influenced by their behaviour as greenhouse gases.

- N_2O contributes a minor portion of the overall greenhouse gas emissions in the $NO_x/N_2O/VOC/O_3$ inventory and is, therefore, of relatively minor importance for consideration of management measures.

- The previous conclusions suggest that the objectives of managing the NO_x/VOC/O_3 portion of the overall greenhouse gas issue are essentially congruent with those of NO_x/VOC management for control of peak ground level ozone levels (the National NO_x/VOC Management Plan). Some exceptions were noted in Chapter 5. Control of these gases will produce a greenhouse bonus.

- When the abatement objectives of the NO_x/VOC Management Plan are expressed in terms of CO_2 equivalents, the collective contributions of the most probable reduction measures for anthropogenic emissions will be about 10% of the total greenhouse impact of the anthropogenic NO_x/VOC/O_3 emissions. This estimate includes both high and low cost options.

- The single most effective measures are that are known to have relatively low costs and low barriers to implementation lie in the road transportation sector. These measures include reduced gasoline volatility, tighter emission standards for motor vehicles, and an inspection and maintenance program for vehicles.

- It is obvious, but bears repeating, that all of the possible management measures for NO_x/VOC/O_3 as greenhouse gases must be considered in the context of the management measures for the other classes of greenhouse gases, especially CO_2, and also in the context of the National NO_x/VOC Management Plan.

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8.0 GLOSSARY

ARB	(California) Air Resources Board
BACT	Best Available Control Technology
CAA Amendments	(United States) Clean Air Act Amendments of 1990
CCAA	California Clean Air Act
CCME	Canadian Council of Ministers of Environment
CCME Plan	CCME Management Plan for Nitrogen Oxides and Volatile Organic Compounds
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
EC	European Community
ECE	Economic Commission for Europe of the United Nations
EPA	(United States) Environmental Protection Agency
Greenhouse Gas	any gas which is radiatively active in the infrared region of the spectrum which is thought to contribute to atmospheric, thus, global warming
GVRD	Greater Vancouver Regional District
GWP	Global Warming Potential (specific context of the IPCC Scientific Assessment)
HDV	Heavy duty vehicle
I/M program	(Vehicle) Inspection and maintenance program
IPCC	Intergovernmental Panel on Climate Change (World Meteorological Organization and United Nations Environment Program agency)
kt	kilo tonnes
LAER	Lowest Achievable Emission Rate
LDV	Light duty vehicle
LOMEI	Lower Mainland Emission Inventory
LPG	Liquefied petroleum gas (mainly propane)
MOE	(B.C.) Ministry of Environment
$\mu g/m^3$	micrograms per cubic meter
mg/m^3	milligrams per cubic meter
NEIS	(Canadian) National Emissions Inventory System
NESCAUM	North East States for Coordinated Air Use Management
NMHC	Non-methane hydrocarbons
NO_x	Nitrogen oxides - nitric oxide and nitrogen dioxide
N_2O	Nitrous oxide
NSPS	New Source Performance Standard
O_3	Ozone
PM_{10} (PM10)	Specific class of particulate matter emissions - particles smaller than ten micrometers in diameter
ppb	parts per billion by volume (1 part contaminant per billion parts of air)
ppm	parts per million by volume (1 part contaminant per million parts of air)
RACT	Reasonable Available Control Technology
RDIS	Residual Discharge Information System
ROG	Reactive organic gases (non-methane hydrocarbons plus other volatile organic compounds)
RVP	Reid Vapour Pressure (of gasoline)

SCAQMP	South Coast Air Quality Management Plan
SCC	Source Classification Code (used in conjunction with emission inventories)
SIC	Standard Industrial Classification Code (Canadian/Statistics Canada and US versions differ somewhat)
t	(metric) tonne
THC	Total hydrocarbons
TMP	Thermo-mechanical pulping
UTM	Universal Transverse Mercator cartographic coordinate system used for some inventory systems
VMT	Vehicle miles travelled (kilometers used in Canadian inventories)
VOC	Volatile organic compounds (equivalent to non-methane hydrocarbons)

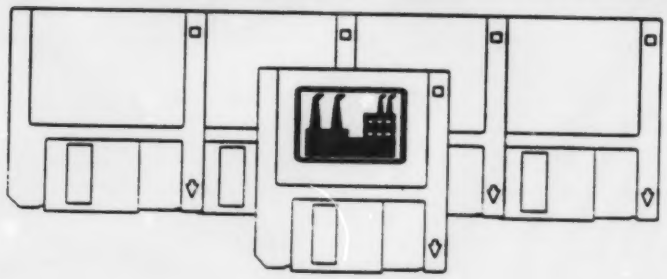
APPENDIX A: RESIDUAL DISCHARGE INFORMATION SYSTEM

The following are excerpts from Environment Canada's draft version (April, 1991) of the user's guide to the Residual Discharge Information System (RDIS).

Appended are an introduction to the system and a general overview.

RDIS

RESIDUAL DISCHARGE INFORMATION SYSTEM



Environment Canada Environment Canada

Chapter 1

Introduction

What Is RDIS

RDIS is an acronym for Residual Discharge Information System. This micro-computer based system was designed to enable the compilation of emissions inventories, for diverse - pollutants. It was designed with easy to use menus, to simplify the tasks of entering and reporting emissions data on a yearly basis.

Emission information for both anthropogenic and non-anthropogenic sources are maintained within the system and enable the coverage of all the important sources of pollution in Canada. Since not all sources of pollution can be monitored, the system uses the concept **discharge factor** to automatically calculate the emissions from the sources for which emission data for specific pollutants are not available. With this discharge factor, which indicates the rate at which a contaminant is released to the environment as a result of some activity, the system as the capability to present a more complete picture of the emissions released at the provincial or national levels.

The RDIS is also equipped with some additional processing capabilities such as the speciation of Volatile Organic Compounds (VOC), and the griding of emissions which are required for activities such as emission modelling.

Hardware Requirements

The minimum hardware and software requirements your computer system needs to run RDIS are:

-> MS-DOS or PC-DOS compatible computer (AT or 386 compatibles).

-> MS-DOS or PC-DOS version 3.1 or later.

-> 1.2 megabyte 5.25" or 1.44 megabyte 3.5" floppy drive.

-> A hard disk with at least 20 megabytes of storage since the system requires a 3 to 5 megabytes of data per year depending on the province.

-> A wide carriage return printer with condensed mode capabilities.

-> The DOS config.sys file should have buffers=20 and files=40.

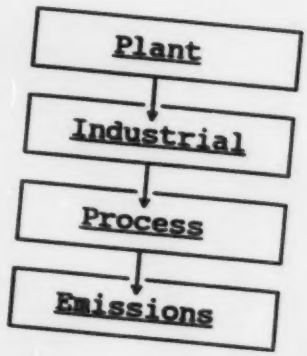
The hard disk requirements will also be greater if the VOC speciation and/or griding modules of the system are used. These modules create new files that can be used for further processing or reporting.

RDIS Overview

System Structure Description

The system is made up of a multitude of dBaseIV programs and of two types of data files that we qualify as related and primary. The related files are used as dictionaries within the system to define the various codes, while the primary files contain the actual inventory data. Although there are only 4 primary files, the gist of the system revolves around them. These primary files includes 4 main groups of information that we call data blocks.

-These blocks are named:



-The Plant data block includes basic location information for each plant such as thier address, city, lat/long. Other useful information like the plant contact person and its telephone number are also included.

-The Industrial data block includes information that characterises the industrial activities performed at the plant. It also includes temporal information required for modelling activities such as hourly and daily schedules of operations.

-The **Process data block** contains a description of the process along with some operational parameters required to perform emission estimates. Information on boiler types, fuel characteristics, process equipment, and the quantity of material produced are some of these useful parameters.

-The **Emissions data block** contains process specific emission data. Information such as the control device types, their efficiencies along with the quantity of pollutant released are all maintained in this data block. Details on the method used to obtain the emission values such as stack sampling tests, permit data, engineering estimate which are useful to analyze the accuracy of the emission quantities are also part of this block.

A key item is used in each of the above data blocks to retrieve information. The different key items used are:

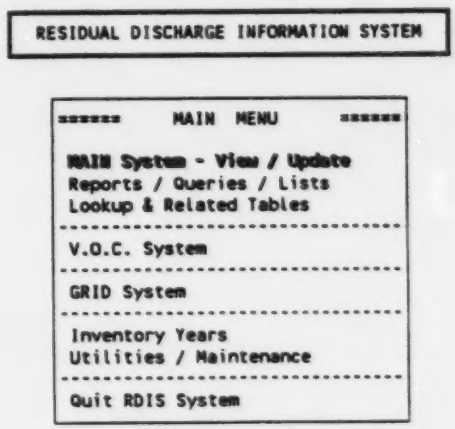
Data Block	Key Item
Plant block	plant code
Industrial block	Standard Industrial Code (SIC)
Process block	process code
Emission block	pollutant code

The interrelation between the data blocks is a one to many relationship. This translates into saying that each plant can have many industrial activities, and that each activity can have one or many processes, and each processes can have one or many pollutants emitted.

Six Steps To Obtain A Plant Information Summary

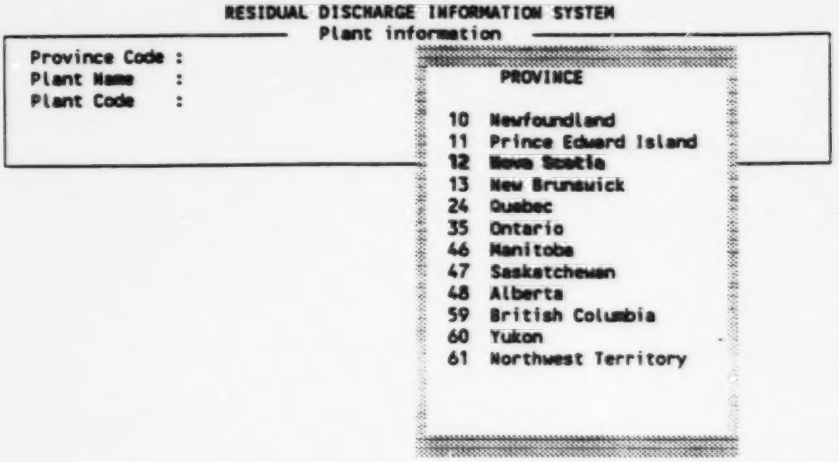
To gain an appreciation of what the system is about and experiment further with the above mentioned navigating keys, lets try a quick example that will enable you to obtain on one screen a summary of the information available for a given plant.

Step 1 **The Main Menu**



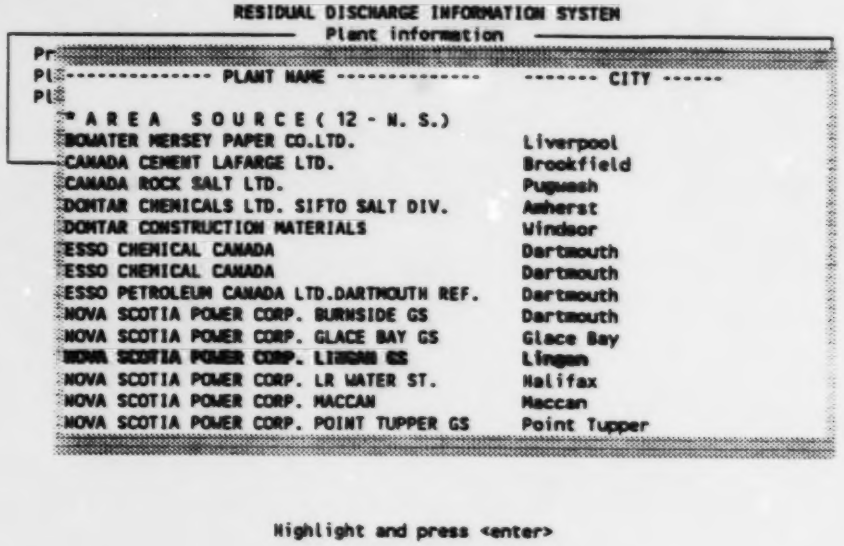
We are now ready to proceed with our example. Using the Up Arrow and Down Arrow keys select the first option on the main menu **MAIN System - View / Update**. A new screen then appears permitting the selection of a source.

Step 2 The Province Selection



The easiest way to select a source is to hit the **F1** key to obtain a list of the provinces available on your copy, and then with the Up Arrow and Down Arrow keys highlight the desired province and hit Enter (if only your province is available on your copy simply hit Enter). This simple selection procedure is the same for all selection windows of the system.

Step 3 **The Plant Selection**

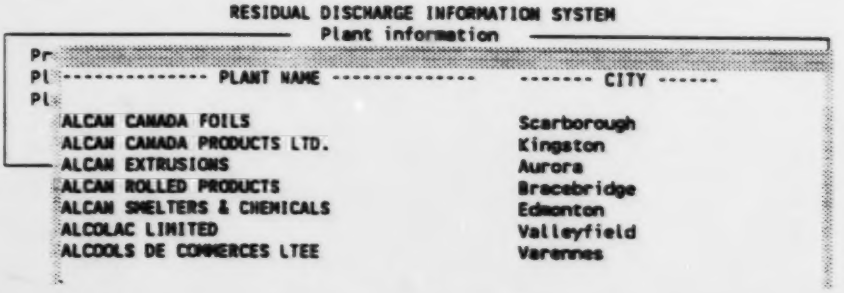

RESIDUAL DISCHARGE INFORMATION SYSTEM
Plant information
PLANT NAME
CITY
* A R E A S O U R C E (12 - N. S.)
BOWATER MERSEY PAPER CO.LTD. Liverpool
CANADA CEMENT LAFARGE LTD. Brookfield
CANADA ROCK SALT LTD. Pugwash
DOMTAR CHEMICALS LTD. SIFTO SALT DIV. Amherst
DOMTAR CONSTRUCTION MATERIALS Windsor
ESSO CHEMICAL CANADA Dartmouth
ESSO CHEMICAL CANADA Dartmouth
ESSO PETROLEUM CANADA LTD.DARTMOUTH REF. Dartmouth
NOVA SCOTIA POWER CORP. BURNSIDE GS Dartmouth
NOVA SCOTIA POWER CORP. GLACE BAY GS Glace Bay
NOVA SCOTIA POWER CORP. LINGAN GS Lingan
NOVA SCOTIA POWER CORP. LR WATER ST. Halifax
NOVA SCOTIA POWER CORP. MACCAN Maccan
NOVA SCOTIA POWER CORP. POINT TUPPER GS Point Tupper
Highlight and press <enter>

A list of the plants for the province selected will then be presented and again with the arrow keys the desired plant can be selected by hitting the ENTER key on the highlighted plant.

The above two steps can be simplified to one if:

a) the user knows the code of the desired plant (RDIS code or provincial code), it can be entered directly in the **Plant Code** area;

b) the beginning letter(s) of the name of the plant desired can be entered and a list of plants starting with those letters will be displayed (ex. entering ALC at the **Plant Name** area).



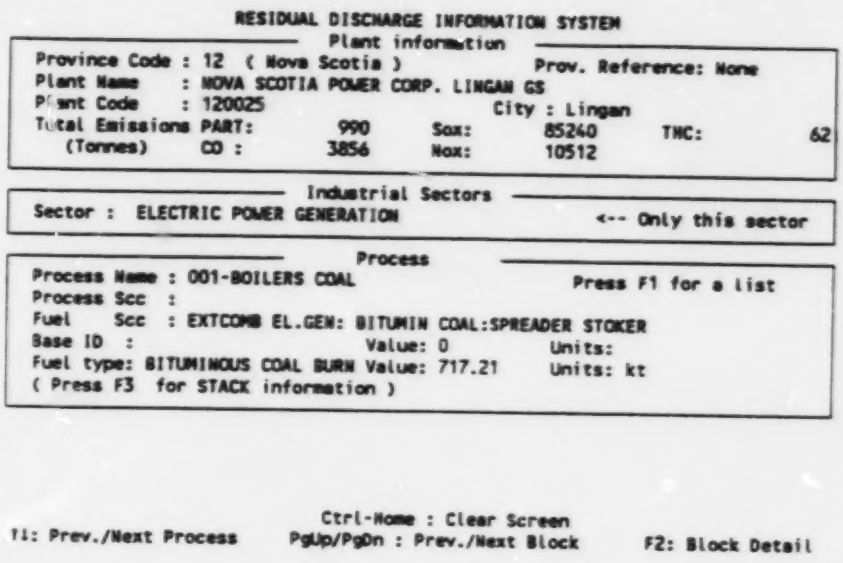
Step 4 **The Industrial Data Block**

```
                    RESIDUAL DISCHARGE INFORMATION SYSTEM
                              Plant information
 Province Code : 12  ( Nova Scotia )              Prov. Reference: None
 Plant Name    : NOVA SCOTIA POWER CORP. LINGAN GS
 Plant Code    : 120025                          City : Lingan
 Total Emissions PART:      990      SOx:      85240      THC:        62
    (Tonnes)     CO :      3856      Nox:      10512
                            Industrial Sectors
 Sector :  ELECTRIC POWER GENERATION                  <-- Only this sector

          Ctrl-Home : Clear Screen          Ctrl-PgDn : Quick Update
 ↑↓: Prev./Next Sector      PgUp/PgDn : Prev./Next Block      F2 : Block Detail
```

Although a list of keys are listed at the bottom of the screen, we will limit ourselves to the use of the Page Down and the F1 key at the moment. Hitting the Page Down key at this point will display the first industrial sector of the plant. A list of the other industrial sectors can be obtained using the F1 key if other sectors exits. By highlighting the desired industrial sector and hitting the Enter key a selection can be made. In the case of our example above, the F1 key is not available since there is only one sector. The system also displays a message " <-- Only this sector " to indicate this situation.

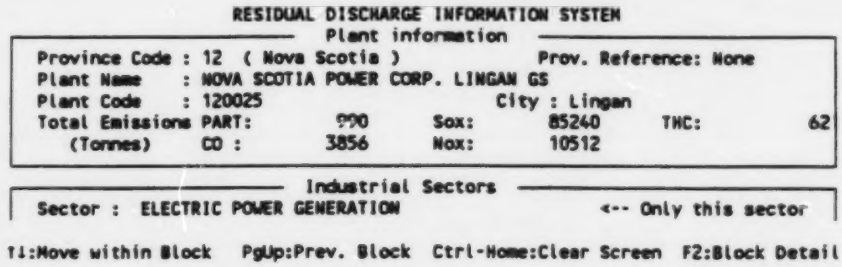
Step 5 The Process Data Block


RESIDUAL DISCHARGE INFORMATION SYSTEM
Plant information
Province Code : 12 (Nova Scotia)
Prov. Reference: None
Plant Name : NOVA SCOTIA POWER CORP. LINGAN GS
Plant Code : 120025
City : Lingan
Total Emissions (Tonnes) PART: 990 Sox: 85240 THC: 62
CO : 3856 Nox: 10512
Industrial Sectors
Sector : ELECTRIC POWER GENERATION
<-- Only this sector
Process
Process Name : 001-BOILERS COAL
Press F1 for a list
Process Scc :
Fuel Scc : EXTCOMB EL.GEN: BITUMIN COAL:SPREADER STOKER
Base ID :
Value: 0
Units:
Fuel type: BITUMINOUS COAL BURN Value: 717.21
Units: kt
(Press F3 for STACK information)
Ctrl-Home : Clear Screen
F1: Prev./Next Process
PgUp/PgDn : Prev./Next Block
F2: Block Detail

As it was mentioned earlier each plant can have a multitude of processes for each industrial activity. By hitting the Page Down key the first process for the selected industrial sector will be displayed. A list of the other processes can be obtained by using the F1 key.

Note: The stack parameters for the displayed process can also be viewed at this stage by hitting the F3 key (only available for process which are linked to a stack).

Step 6 The Emissions Data Block


RESIDUAL DISCHARGE INFORMATION SYSTEM
Plant information
Province Code : 12 (Nova Scotia) Prov. Reference: None
Plant Name : NOVA SCOTIA POWER CORP. LINGAN GS
Plant Code : 120025 City : Lingan
Total Emissions PART: 990 Sox: 85240 THC: 62
(Tonnes) CO : 3856 Nox: 10512
Industrial Sectors
Sector : ELECTRIC POWER GENERATION <-- Only this sector
↑↓:Move within Block PgUp:Prev. Block Ctrl-Home:Clear Screen F2:Block Detail

Hitting the Page Down key will make the emission data block appear on the screen. With this block displayed, one can have a global idea of the kind of information the system contains.

As you can see by the optional keys listed at the bottom of the screen, more detailed information can be viewed and edited with the use of the F2 key. If you want to try this example with another plant, you can hit the Ctrl-Home keys simultaneously to clear the screen and get to the plant data block for a new source selection.

Appendix B

Source Category / Industrial Sector Classification

Source Category / Industrial Sector	SIC Name	SIC
Industrial Processes		
Cement and Concrete Manufacture	Cement and Concrete Industry	35210
Forestry		
Pulp & Paper Industry	Kraft (Sulphate) Pulping	27110
	Neutral Sulphite Pulping	27109
	Newsprint	27120
	Other Paper Converters	27400
	Pulp and Paper Industry (Non-class)	27100
	Sulphite Pulping	27111
	Thermo-Mechanical Pulping	27108
Wood Industry	Forest Services Industry	05110
	Hardwood Plants	25210
	Logging Industry	04110
	Paperboard Industry	27130
	Particle Board Industry	25920
	Plywood & Veneer	25200
	Pulpboard Plants	25201
	Sawmills	25120
	Shingle and Shake Industry	25110
	Wood Preservation Industry	25910
	Wooden Box and Pallet Industry	25610
	Wooden Door and Window Industry	25430
	Misc. Wood Industries	25900
Mining		
Asbestos Production	Asbestos Production	06210
Coal Industry	Coal Industry	06300
Mining and Rock Quarrying	Limestone Quarries	08120
	Mining and Rock Quarrying	09290
	Molybdenum Mines	06150
Oil & Gas Production		
Crude Oil Production	Conventional Crude Oil and Nat Gas	07113
Natural Gas Processing	Natural Gas Processing Industry	07110
Tar Sands	Non-conventional Crude Ind.	07120
Other Industrial Fuel Combustion	Industrial Fuel Combustion	56223
Other Industries		
Asphalt Production	Asphalt Production	06210
Bakeries	Bakeries	10720
Clay Products	Clay Product Industry	35111
Grain Industries	Grain Handling & Milling	47110-47113
Paint & Varnish Manufacturing	Paint & Varnish Manufact.	37510
Other Chemicals	Ammonia Production	37130
	Ammonium Nitrate Production	37143

	Ammonium Phosphate	37115
	Ammonium Sulphate	37113
	Chemical Fertilizer & Fertilizer Mtls	37219
	Elemental Phosphorus Production	37112
	Fertilizer Prod Ammonium Nitrate	37210
	Lime Manufacture	35810
	Magnesium Production	29594
	Nitrate Fertilizer - Urea	37220
	Other Manufactured Products Ind.	39990
	Phosphate Acid Prod. Thermal	37118
	Red Phophorus Production	37141
	Salt Production	06250
	Sinlge Superphosphate	37116
	Sodium Carbonate (Soda Ash)	37110
	Sodium Chlorate Production	37142
	Sodium Nitrate Production	37144
	TNT Production	37145
	Triple Superphosphate	37117
Other Industries	Agricultural Implement Industry	31100
	Aircraft & Parts Manufacture	32100
	Asphalt Roofing Manufacturers	27200
	Battery Maufacture	33700
	Brewery Products Industry	11310
	Carpet Mat & Rug Industry	21600
	Coffin & Casket Industry	25810
	Coke Ovens not in Steel Plants	36990
	Confectionery Manufacturing	13100
	Dairy Factories	10500
	Distillery Products Industry	11210
	Electric Wire & Cable	33800
	Engrav. Stereotyping Industry	28700
	Fabric Structure Metal Industry	30200
	Feed Industry	10530
	Feed Manufactures	12300
	Fibre Preparing Mills	21100
	Fish Products Industry	10210
	Flour Mills	12400
	Fluorspar Processing	06291
	Frozen Fruit & Vegetable Industry	10320
	Fruits & Vegs. Canners/Preservers	11200
	Glass Manufacture	35620
	Gold Roasting	06110
	Gypsum Processing	35930
	Heating Equipment Manufacturers	30700
	Industrial Inorganic Chemical Ind.	03711
	Leaf Tobacco Processing	12110
	Leather Tanneries	17200
	Lubricating Oil & Grease Industry	36120
	Major Appliances	33200
	Meat & Meat Products Industry	10110

Metal Rolling Casting, Extruding	29800
Metal Stamp. Press & Coating	30400
Mineral Wool	35400
Misc. Electrical Products	33900
Misc. Machinery Equipment	31500
Misc. Manufacturing Industries	39900
Misc. Metal Fabric. Industry	30900
Misc. Food Industries	13900
Motor Vehicle Manufacture	32300
Mushroom Production	19000
Nepheline Syenite Processing	06292
Non-Metallic Mineral Insulating Mat.	35940
Office, Store Machinery	31800
Other Chemical Products Industries	37990
Other Fabricated Structural Metal Prod	30290
Other Millwork Industries	25490
Other Non-Metal Mineral	35900
Other Transport Services	51700
Other Waste Materials, Wholesale	59190
Paper Box & Bag Manufacturers	27300
Pharmceuticals, Medicines	37400
Phosphate Processing	06290
Plastic Products	16110
Potash Processing	06240
Power Boiler & Heat Exchanger Ind.	30110
Printing & Publishing	28900
Pyrrhotite Roasting	06172
Railroad Roll. Stock Industry	32600
Refactories Industry	35910
Rubber Products Industries	15990
Sand & Gravel Processing (Pits)	08210
Shipbuilding and Repair Industry	32710
Silica Processing	08211
Slaughter & Meat Processing	10100
Soft Drink Industry	11110
Steel Pipe and Tube Industry	29210
Stone Processing	08110
Stone Processing (Building Stone)	35990
Sugar Refineries	13300
Textile Dyeing & Refining	21800
Tire & Tube Manufacturing	16300
Uncoded or Undefined Industrial Act.	99990
Urban Transit Systems	50900
Vegetable Oil Mills	13500
Wineries	14700
Wooden Kitchen Cabinet & Bath.	25420
Wool Yarn Mills	19300
Petrochemical	
Carbon Black	37111
Carbon Black Industry	36900

Petrochemical Industry	Acethaldehyde Production	37139
	Industrial Chemicals (General)	37800
	Ketene Acid Production	37136
	Mixed Fertilizers	37200
	Nitric Acid Production	37114
	Paint and Varnish	37500
	Petrochem	37800-37859
	Petrochemical Industry-Isobutylene	37131
	Plastic & Synthetic Resins Fabrication	37312
	Soap & Cleaning Compounds	37600
	Sulphuric Acid Production	37119
	Synthetic Textile Mills	20100
Plastics & Synthetic Resins Fab.	Plastics & Synthetic Resins Fab. Area	37313
Petroleum Refining	Petroleum Refining	36100
Primary Metals		
Aluminum Production	Aluminum Production	29510
	Carbon & Graphite Electrodes	33990
Copper and Nickel Production	Cu Smelting & Refining	29590
	Ni Smelting & Refining	29592
Ferrous Foundries	Ferro-Alloys Manufacturing	29110
Iron Ore Mining	Iron Ore Mining and Beneficiation	06170
Lead and Zinc Production	Pb Smelting & Refining	29990
	Zn Smelting & Refining	29992
Fuel Combustion		
Commercial Fuel Combustion	Commercial Fuel Combustion	56222
	Commercial Printing	28600
	Correctional Services	81220
	Defence Services	90200
	Department Stores	64200
	Education Related Services	80900
	Elementary & Secondary Schools	80100
	Gas Distribution	54700
	General Administrative Services	83590
	General Hospitals	86110
	Greenhouse Products	01630
	Hotels and Motor Hotels	91110
	Hotels, Restaurant, Taverns	87500
	Insurance, Real Estate Agencies	73500
	Local Administration	95100
	Other Bus. Manag. Services	86900
	Other Governemnt Services	99100
	Other Health Services	82700
	Other Miscellaneous Services	89900
	Other Recreational Services	85900
	Other Repair Services	99490
	Paint and Body Repair Shops	63520
	Religious Organizations	83100
	Research Administration	82760

		Savings Credit Institutions	70200
		Sports & Recreation Clubs & Services	96530
		Sports & Recreation Clubs	96590
		Universities & Colleges	80500
	Electric Power Generation	Electric Power Generation	49110
	Residential Fuel Combustion	Apartment Gas-Oil-Coal	99210
		Religious Organizations	98110
		Residential Fuel Combustion	56221
	Residential Fuelwood Combustion	Residential Fuelwood Combustion	56224
Transportation			
	Aircraft	Aircraft	45110
	Automobiles	Gasoline Powered Automobiles	45890
	Heavy-Duty Diesel Vehicles	Heavy-Duty Diesel Vehicles	45604
	Heavy-Duty Gasoline Trucks	Heavy-Duty Gasoline Trucks	45601
	Light-Duty Gasoline Trucks	Light-Duty Gasoline Trucks	45600
	Light-Duty Diesel Trucks	Light-Duty Diesel Trucks	45603
	Marine	Marine	45400
	Motor Cycles	Gasoline Powered Moter Cycles	45891
	Off-Road Use of Gasoline	Off-Road Use of Gasoline	45894
		Snowmobiles	45892
	Other Diesel Vehicles	Other Diesel Vehicles	45602
	Railroads	Railroads	45310
	Tire Wear	Tire & Tube Industry (Tire Wear)	15111
Incineration			
	Other Incineration	Commercial Incin. (Solid Waste)	49993
		Industrial Incineration (Solid Waste)	49992
		Municipal Incineration	49990
		Other Utilities (Incineration)	57900
		Sewage Sludge Incineration	49991
	Wood Waste Incineration	Wigwam Burners	04111
Miscellaneous			
	Application of Surface Coatings	Painting & Decorating	42751
	Cigarette Smoking	Other Tobacco Prod. (Smoking)	12220
	Dry Cleaning	Dry Cleaning Plants	97211
	Fuel Marketing	Diesel Oil Marketing	51112
		Gasoline Fuel Marketing	51111
	General Solvent Use	General Solvent Use	65321
	Pesticides and Fertilizer Application	Other Services Incl. Agricultral Crops	02290
		Pesticides (Crop Dusting & Spraying)	02220
	Slash Burning	Slash Burning	04120
	Structural Fires	Firefighting Services	82240
	Transmission Lines	NA	NA
	Anesthetics/Aerosols	NA	NA
	Water Treatment	NA	NA
Open Sources			
	Agricultural Operations	Agricultural Wind Erosion & Tilling	02390

Animal Waste	Animal Waste	02190
Construction	Bridge, Road Construction	41210
	Excavating & Grading	42141
	Heavy Construction	41190
	Non-Residential Construction	41200
	Residential Construction	40110
	Water, Sewer, Construction	41220
Dust From Paved Roads	Dust From Paved Roads	45911
Dust From Unpaved Roads	Dust From Unpaved Roads	45893
	Truck Transportation on Gravel Roads	45610
Forest Fires *	Other Forestry Services (Forest Fires)	05120
Mine Tailings	Mine Tailings	09291
Human Waste	NA	NA

* Forest fires are considered as biogenic sources for the purposes of this study and therefore not included as open (anthropogenic) sources.

APPENDIX C

SUMMARY OF THE METHODOLOGIES USED TO CALCULATE N_2O EMISSIONS

CALCULATION OF N_2O POINT AND AREA SOURCE EMISSIONS USING THE RESIDUAL DISCHARGE INFORMATION SYSTEM (RDIS)

Note: In the following, commands typed within { } refer to options the user may select from RDIS menus.

Since RDIS presently does not include N_2O, we had to incorporate this pollutant into the system, proceeding as follows:

First, all plants included in RDIS and situated in the Lower Mainland were deleted from the databases system. This was necessary in order to avoid data redundancies when data from LOMEI (Lower Mainland Emission Inventory) were to be incorporated into the resulting files.

In order to summarize the data RDIS provided, several new files were created from the various data files in RDIS to pull the needed information together and to better identify processes, base quantities, units, and the like.

Not needing to reach the plant-specific level to estimate the emissions of N_2O, we calculated emissions on the SCC level. RDIS differentiates between fuel SCCs and base SCCs. Therefore, a selection of SCCs had to be made from these files. We selected all SCCs occurring in British Columbia with NO_x emissions >0, although there are some variations to this.

Using the selected SCCs and having corrected fuel quantities and discharge units for a number of processes, we created an N_2O emission factor file which was later appended to the RDIS emission factor file. RDIS provides more than 10 different emission calculation/estimation methods. In our case, the actual emission calculations were carried out using the option {Utilities/Maintenance} {Calculate Emissions with NAPAP} {For a Contaminant} within RDIS. This option makes use of a file which contains US EPA NAPAP emission factors, and it is to this file to which our emission factors were appended. SCCs and emission factors may be added, deleted or changed here, but only <u>one</u> emission factor may be assigned to each listed fuel or base SCC.

Because RDIS only accepts compatible units, our emission factors had to be converted to the units RDIS used for each SCC. Some units could not be converted (for example: RDIS factor for wood= kg pollutant per coating line; our factor for wood = kg pollutant per t of wood).

For the time being, the only available N_2O emission factors for point sources are factors for the stationary combustion of coal, oil, gas or wood. These can be applied directly to calculate the emissions once the type of fuel and the fuel units of a process have been identified. However, where production quantities (such as emissions per tons of ore mined, coal dried, gas, P_2O_5 or air dried pulp produced) rather than fuel quantities were given, a direct application of our emission factors was not possible. In these cases, N_2O emissions were calculated for the fuel combustion part of a process alone or an emission factor was derived by assuming that N_2O (production

based)/N_2O (fuel based) emission ratios are equivalent to NOx (production based)/NO_x (fuel based) ratios. (The equation can be solved for a N_2O (production based) emission factor):

N_2O emissions from fuels:
For a given fuel SCC, the base quantity and the base quantity name were identified using lookup files provided in RDIS. N_2O emissions were then calculated using the emission factor for the corresponding fuel. No emission factors were assigned to SCCs with unidentified fuels or with incorrect units where these could not be determined. For solid waste incineration the factor for burning wood was used.

N_2O emissions from processes:
For emission sources which had been assigned both a base and a fuel SCC, N_2O emissions were calculated for the fuel combustion part of the process only. In most cases, a base SCC was associated with a fuel SCC with one given fuel. Some fuel SCCs, however, apparently serve as summary categories and include several different fuels. Since only one factor per SCC can be input to the RDIS emission factor file, we had to determine the fuel which was most commonly used and apply the appropriate emission factor.

Several base SCCs were not associated with fuel SCCs. The following two examples illustrate in detail how an emission factor for these categories was calculated:

EXAMPLE 1:

SCC = 31000293: Natural Gas Production.
Processname: natural gas fired compressors

1) NO_x emission factor for natural gas fired compressors (taken from RDIS):
--> 54464 kg NOx/MM m3 of gas

2) N_2O emission factor for burning of natural gas:
--> 13.884 kg N2O/MM m3 of gas

The N_2O factor for burning natural gas is 0.0255 % of the NO_x emission factor.

3) NO_x emission factor for natural gas fired compressors in gas production (taken from RDIS):
--> 4804.69 kg /MM m3 of gas produced

4) The derived N_2O emission factor for natural gas production is:
--> 0.0255 % * 4804.69 kg NO_x/MM m3 of gas produced.
--> 1.2248 kg N_2O/MM m3 of gas produced.

EXAMPLE 2:

SCC = 30700194: Pulp production
Processname: Recovery boilers for air dried pulp production

For a total of 23 listed processes only 5 were associated with a fuel SCC (10201201: burning of solid waste). In order to calculate the emissions for all processes within this SCC, an emission factor for the base SCC was calculated using the method shown below and assuming that all sources burn oil. The fuel SCCs for these sources had to be deleted from the files for reasons already mentioned above.

1) NO_x emission factor for recovery boilers fired with grade 6 oil (taken from RDIS):
--> 6.59 kg NO_x / m3 of oil

2) N_2O emission factor for burning of oil:
--> 0.08277 kg N_2O / m3 oil

The N_2O factor for firing recovery boilers is 1.25 % of the NO_x emission factor.

3) NOx emissions factor for recovery boilers for air dried pulp production (taken from RDIS):
--> 0.95 kg/t of air dried pulp produced

4) The derived N_2O emission factor for natural gas production is:
--> 1.25 % * 0.95 kg NOx/t air dried pulp produced
--> 0.01193 kg N2O/t air dried pulp produced.

Gridding N_2O Emissions with RDIS

The emissions were put on the 127 * 127 km2 grid by selecting the menu points {Grid system} {Generate emissions by grid} {Common pollutants} and choosing "nitrous oxide" from {Pollutant list}.

First, however, the grid file had to be prepared by selecting {Grid system} {Prepare the "127 km2" grid file}, a utility which prepares the prorating factors which serve to distribute the emissions over the province. The resulting file lists emissions per SIC and grid square.

Since grid square # 67 (row=45, col=42) lies completely outside of BC, and e emissions allocated to it stem from a BC community, its emissions were added to the adjacent grid square # 55 (row=44, col=42).

Then the N_2O emissions were totalled for each of the 80 grid squares to a summary grid file which also contains all anthropogenic and biogenic emission sources for NO_x, VOC, and N_2O. Finally, after all emissions had been compiled, reviewed and edited, all anthropogenic and all biogenic N_2O, VOC and N_2O emissions were converted to CO_2 equivalents and added for each grid square.

Incorporating Data from the LOMEI (Lower Mainland Emission Inventory) into the Gridded System

Using a converted data file from the GVRD, we estimated N_2O point source emissions as a percentage of NO_x emissions. The file included a list of permitted point sources, their NO_x emissions, the type of fuel burned, SCCs, and in a few cases the actual fuel quantity burned. The total NO_x emissions in the file account for 97.3 % of the Lower Mainland point source NO_x emissions (as reported in one of the Lower Mainland Emissions Inventory Report volumes).

The methodology applied:

For every SCC in the GVRD point source emissions file we looked for an uncontrolled NO_x emission factor in RDIS. We then calculated the ratio:

N_2O emission factor for the combustion of the fuel used/NO_x emissions factor for the given SCC, and multiplied this fraction by the NO_x emissions in the GVRD point sources file.

We used this number as a crude approximation of the N_2O emissions.

In many cases, however, a specific SCC in the GVRD point source emissions file was not included in RDIS. Thus, we often didn't have a NOx emission factor for a given SCC. In these cases, we averaged the N_2O/NO_x ratios obtained above for all plants burning the same fuel. Where the fuel type was unidentified, an average ratio for both oil and gas fuels was assigned to the appropriate SCC.

Averaging N_2O/NO_x ratios for plants burning the same type of fuel:

Fuel burned	
Natural gas	---> 0.00745 (4)
Hog fuel, wood waste	---> 0.16416 (5)
Oil	---> 0.01647 (3)

Others (unidentified) ---> average of gas/oil averages: 0.012

(In parentheses: number of SCCs averaged)
The averaging of factors, however crude, does reflect that gas is the cleanest fuel, followed by oil, and that wood has the greatest N_2O emissions.

Eliminating Data Redundancies Between RDIS and LOMEI

Redundant data (refer to sections 3.0 and 3.4 of the report for a detailed analysis) were deleted directly in RDIS files and in the final grid summary file, and, where appropriate, were redistributed to the rest of the province using the most appropriate prorating factors.

CALCULATION OF N_2O EMISSIONS FROM SOURCES NOT (OR ONLY PARTIALLY) INCLUDED IN RDIS

Power Line Coronas

A) N_2O Emission Estimates from Power Lines

N_2O emissions from high voltage transmissions lines were estimated for circuits greater than 138 kV according to the method outlined in Hill et al (1984). They are a function of line voltage, line loss and line length. The data for B.C. were provided by B.C. Hydro.

Length of Transmission Lines in British Columbia

Length of 500 kV transmission lines	: 5344 km (3313.28 miles)
Length of 360, 287 and 230 kV transmission lines	: 3927 km (2434.74 miles) (mostly 230 kV lines)

Source: B.C. Hydro (Doug Cave: 293-5802, K.C. Lee: 663-4227).)

The average corona loss and N_2O emissions from high voltage power lines in the United States for the year 1980 were estimated in Hill (et al, 1984) as follows:

Mean line voltage (kV)	circuit miles	average corona loss in kW/mile	average corona loss in J/year
362	35451	3	3.354E15
550	17687	6	3.347E15
800	3077	13	1.260E15

From this it may be inferred that:

Corona loss (J/yr) = circuit miles * average corona loss (kW/mile) * 3.15333E10

Corona Losses Estimated by B.C. Hydro
(typical yearly values for foul and fair weather)

for the 500 kV lines:	3.48 kW / km = 5.6 kW / mile
for the 360, 287 and 230 kV lines:	2 kW / km = 3.2 kW / mile

Source: B.C. Hydro (K.C. Lee: 663-4227).

Thus, the estimated corona loss for British Columbia is:

[(3'313.3 * 5.6) + (2'434.7 * 3.2)] * 3.15333E10 = 8.3E14 J/yr

In Hill (et al, 1984) an N_2O production efficiency of approximately 4E16 molecules per joule is assumed for high voltage power lines.

Thus, for British Columbia, an estimated 8.3E14 * 4E16 = 3.3E31 molecules N_2O are produced on average per year.

From Hill (et al, 1984) it further follows that 3.2E32 molecules of N2O are equivalent to 23'000 t of N_2O. Therefore, 3.3E31 molecules amount to 2'388.4 t N_2O.

Using the above data, we conclude that roughly 2'400 t N_2O are generated per year from high voltage power lines in British Columbia. Using a B.C. Hydro Survey Map (1990), the transmission line corridors and their locations within the grid were identified and the N_2O emissions allocated accordingly.

B) Ozone and NO_x Emission Estimates from Power Lines

In Roche et al (1973), experimentally determined ozone and NO_x production rates for single and bundle transmission line conductors in dry and wet corona are given as follows:

Ozone: from $0.31E^{-2}$ lb/kWh corona loss to $0.81E^{-2}$ lb/kWh corona loss ($1.406E^{-3}$ to $3.67E^{-5}$ kg/kWh corona loss)

NO_x: from $0.073E^{-2}$ lb/kWh corona loss to $0.09E^{-2}$ lb/kWh corona loss ($3.31E^{-4}$ to $4.08E^{-4}$ kg/kWh corona loss)

Applying the methodology outlined above for N_2O to these numbers, the yearly production rates of ozone and NO_x from transmission lines in British Columbia are estimated at :

325 tonnes to 850 tonnes of ozone per year, and 75 tonnes to 95 tonnes of NO_x per year.

N_2O Emissions from the Application of Nitrogen Fertilizers

A certain percentage of nutrient-N in fertilizers containing nitrogen is emitted as atmospheric N_2O upon application. We estimated this loss of nitrogen as N2O from N-fertilizers at 1.2 % of the nutrient N applied (Environment Canada, 1991b; Anderson et al, 1987; Eichner, 1990; Conrad et al, 1983).

Because it was not clear what kind of fertilizers were included in RDIS, we calculated N_2O emissions from N-fertilizers using another source. The Western Canada Fertilizer Association in Surrey provided the following statistics:

- Nitrogen (N) fertilizers sales in B.C. by region (Central and South B.C. and the Peace River

Block),
- Nitrogen N fertilizers used in BC by region

The amount of plant nutrients (in this case nitrogen) may be obtained by multiplying retail fertilizer sales for different nitrogen containing fertilizers by their N-content.

Nitrogen Content of Different Fertilizers

Anhydrous ammonia	: 82 %
Urea	: 46 %
Ammonium nitrate	: 34 %
Ammonium sulphate	: 20 or 21 %
M.AmP.	: 11 %
D.A.P.	: 18 %
A.P.S.	: 16 %
Nitrogen solution	: 28 %

Source: Western Canada Fertilizer Association; Retail Fertilizer Sales Survey.

The results are shown in the following table:

NITROGEN (N) FERTILIZERS - EXPRESSED AS TONNES OF NUTRIENT N - USED IN BC BY REGION AND ESTIMATED EMISSIONS OF N_2O (IN PARENTHESES). YEAR ENDING JUNE 30, 1985 - 1990:

	Central + South B.C.	Peace River Block B.C.	Total B.C.
1985	15'734 (188.8)	11'691 (140.3)	27'425 (329.1)
1986	15'520 (186.2)	18'017 (216.2)	33'537 (402.4)
1987	14'707 (176.5)	12'265 (147.2)	26'972 (323.7)
1988	14'315 (171.8)	16'227 (194.7)	30'542 (366.5)
1989	16'816 (201.8)	23'350 (280.2)	40'166 (482.0)
1990	15'841 (190.1)	13'828 (165.9)	29'669 (356.0)

Because of limited available data, these fertilizer-based N_2O emission estimates do not include potential emissions resulting from the application of manure. In some parts of B.C., such as the Fraser Valley, where the field application of manure is appreciable, N_2O emissions may be significant.

Biogenic N_2O Emissions from Soils (Excluding Emissions from the Application of Fertilizers)

Our gridded files use the grid structure provided by Environment Canada. In order to be able to

overlay this grid on a soil map (Farley, 1979), we photocopied and enlarged a map showing the same grid system that is used for RDIS. From this enlargement, a clear film (overlay) was produced. Then, after numbering the grid squares on the overlay, the percentage of land or water outside the BC land mass (Pacific Ocean, Alaska, Yukon, Northwest Territories, Alberta or the United States) was estimated for each of them.

The emission factors (for N_2O and NO_x*) used are:

Soil order	N_2O flux (kg N_2O-N/km^2/y)	NO_x flux (kg NO_x-N/km^2/y)
Chernocemic	107.4	2.6
Solonetzic	44.9	12.2
Luvisolic	27.2	5.8
Podsolic	225.4	272.8
Brunisolic	47.0	20.0
Regosolic	6.7	0.4
Gleyosolic	26.3	0.7
Organic	157.9	156.4
Rockland	5.0	0.3

* The described methodology also applies to NO_x.

Using the soil map, and for each of the 80 grid squares, we then estimated the percentage that different soil orders cover of the BC land mass.

All information was stored in a file. Dominantly lithic soils were categorized under the heading "rockland". The emission factors were applied to all soil orders with the exception of cryosolic soils, for which there were no emission factors available.

Error sources:

Judgement error from visual estimation of the percentage of BC's land mass or the area covered by different soil orders within each grid square. As an aid, we subdivided a grid square into 16 parts and used it as a second overlay.

The enlargement of the map showing the grid system shows a distortion error when overlaid on the soil map.

A comparison of the results presented here with the estimates made by Environment Canada (1981b) follows:

a) Comparison of estimated total land area within B.C.:

	Area in km^2	Difference
Actual area (Farley, 1979)	948000 km^2	-
Area estimated here (*)	972300 km^2	+ 2.6 %
Area estimated (Environment Canada, 1981b)	886194 km^2	- 6.5 %

(*) Area includes all freshwater bodies within B.C.

Since freshwater bodies cover about 2 % of the province (Farley, 1979), the additional estimation error of our total is not greater than 5 %.

b) Comparison of N_2O emissions for B.C. from different soil orders:
(Emissions are in t N_2O-N. To convert to t N multiply by 14/44).

Soil Order	Greenhouse Gases Inv.	Env. Canada (1981b)
Luvisols	6140	6500
Regosols	13.5	13
Podsols	91170	40266
Organic	2185	6186
Brunisols	8754	5950
Rockland	198	1175
Gleyosolic	515	142
Chernosem	1408	2272
Solonetzic	113	43
Total	~ 110500	~ 62500

The total emissions differ by a factor of about 1.75. Since both our study and Environment Canada (1981b) use the same emission factors, the differences are solely due to the area estimations made for different soil orders. The largest absolute difference being the estimated area of podsols - Greenhouse Gases Inventory = 40 % versus 20 % in Environment Canada (1981b) - we asked the B.C. Ministry of Agriculture and Fisheries to confirm or reject our area estimation. We did receive a confirmation of our number for podsols (B.C. Ministry of Agriculture and Fisheries, 1991), however, the reference given used the same source we had used.

N_2O Emissions from Mobile Sources

We worked with the following emission factors from Environment Canada (1991b):

Gasoline		
No catalyst	0.1873 kg/t	= 0.1408 kg/m3 (a)
New catalyst	0.3602 kg/t	= 0.2708 kg/m3
Aged catalyst	1.1931 kg/t	= 0.8971 kg/m3
Diesel	0.2923 kg/t	= 0.2542 kg/m3 (b)

(a) Density of gasoline: 750 kg/m3
(b) Density of diesel : 870 kg/m3

In RDIS, the base quantities given for different vehicle categories are:

- Number of movements for aircraft.
- Number of vehicles for automobiles (light duty gas vehicles), light-duty trucks (gas and diesel powered), motorcycles, heavy-duty trucks (gas and diesel powered).
- Amount of diesel oil burned for railway traffic and for other diesel vehicles in the agricultural, manufacturing, mining, construction, forestry, pipeline and public administration sectors.

To estimate the N_2O emissions of these three categories we proceeded as follows:

N_2O EMISSIONS FROM AIRCRAFT:

N_2O emissions from aircraft were estimated using average fuel consumption factors obtained from the US Environmental Protection Agency (EPA, 1985) for one representative aircraft type in each aircraft class. Given the similar properties of the two fuels, diesel fuel was used as a surrogate for aviation fuel, so that the N_2O emission factor for diesel combustion could be used.

Assumptions: Inflights are 1 hour duration; inflights = number of movements (=LTO) / 2.
Average LTO modes information from the US Environmental Protection Agency (EPA, 1985).

Aircraft class	Representative aircraft type
Jet aircraft	Boeing 737
Turboprop	De Havailland Twin Otter
Piston	Piper Navajo
Small piston	Cessna 150
Helicopters	none found

Aircraft class	Fuel burned/movement (kg)	Fuel burned/inflight (*) (kg)
Jet aircraft	495	1275
Turboprop	39	97.2
Piston	20.6	45.1
Small piston	3.6	11.6

(*) Approach mode for 1hr duration is assumed

N_2O emission calculations:

A) kg N_2O = kg/movement * movements / kg/m3 * kg/t)
(Number of movements from RDIS)

Jet : 495 * 21354 / 870 * 0.2923 = 3.55 t N_2O
Turbo : 39 * 25501 / 870 * 0.2923 = 0.33 t N_2O
Piston : 20.6 * 109578/ 870 * 0.2923 = 0.76 t N_2O
Small piston : 3.6 * 66740 / 870 * 0.2923 = 0.08 t N2O

B) (kg N_2O = kg/inflight * movements * kg/m^3)
Assumption: Inflights = number of movements/2

Jet : 1275 * 21354 / 2 / 870 * 0.2923 = 4.57 t N_2O
Turbo : 97.2 * 25501 / 2 / 870 * 0.2923 = 0.42 t N_2O
Piston : 45.1 * 109578/ 2 / 870 * 0.2923 = 0.83 t N_2O
Small piston : 11.6 * 66740 / 2 / 870 * 0.2923 = 0.13 t N_2O

Total aircraft emissions (A+B) = 10.67 t N_2O

N_2O EMISSIONS FROM VEHICLES

In a first step, we calculated the total fuel consumption per vehicle category in B.C. using the formula:

Fuel consumed = Number of active vehicles in the fleet * VMT * AFC / 100

where: VMT = Average vehicle kilometres travelled per year
AFC = Average fuel consumption per 100 km

The number of vehicles per category was taken from RDIS.

For each vehicle category using gasoline we then obtained the percentage of vehicles with:

- a new catalytic converter

- an aged catalytic converter
- no catalytic converter

and were thus able to apply the emission factors given above. The breakdown of catalytic converter use in 1985 was provided by Environment Canada.

The N_2O emission estimates per vehicle category are as follows:

(kg N_2O = percentage * fuel consumed in m^3 * emission factor in kg/m^3)

Autos (gas)
New catalyst: 0.069 * 2734185 * 0.2708 = 51 t N_2O
Aged catalyst: 0.598 * 2734185 * 0.8971 = 1467 t N_2O
No catalyst: 0.333 * 2734185 * 0.1408 = 128 t N_2O

Light duty trucks (gas)
New catalyst: 0.069 * 1251404 * 0.2708 = 23 t N_2O
Aged catalyst: 0.598 * 1251404 * 0.8971 = 671 t N_2O
No catalyst: 0.333 * 1251404 * 0.1408 = 59 t N_2O

Heavy duty trucks (gas)
No catalyst: 1.000 * 254949 * 0.1408 = 36 t N_2O

Motorcycles (gas)
No catalyst: 1.000 * 17581 * 0.1408 = 2.5 t N_2O

Light duty trucks (diesel)
No catalyst: 1.000 * 71494 * 0.2542 = 18 t N_2O

Heavy duty trucks (diesel)
No catalyst: 1.000 * 936541 * 0.2542 = 238 t N_2O

Total N_2O emissions from vehicles = 2693.5 t

N_2O emissions from marine vessels and off-road gasoline categories could not be estimated due to nonexistent or inappropriate base quantity data. For natural gas powered vehicles, neither base quantities nor total emission estimates are contained in RDIS.

N_2O EMISSIONS FROM RAILWAY TRAFFIC AND OTHER DIESEL VEHICLES

N_2O emissions for the third category were calculated by directly applying the N_2O emission factor for diesel given in the table above to the base fuel quantities provided in RDIS:

Total diesel consumed = 1239400 m^3
Total N_2O emissions = 1239400 * 0.2542 kg/m^3
= 315 t N_2O
Breakdown: 71 t N_2O from railway traffic, 244 t from other diesel vehicles

N_2O Emissions from the Production/Application of Anaesthetics and Aerosols

US production data acquired from the Ontario Ministry of the Environment (1991) was prorated based on population data to estimate N_2O emissions from these sources. The population of BC is approximately 1 % of the US population. The emissions are as follows:

Anaesthetics: 143 t N_2O
Aerosols: 7.5 t N_2O

APPENDIX D

NOx/VOC/O3 GREENHOUSE GAS EMISSION INVENTORY FOR B.C.
MAJOR SOURCE EMISSIONS (by SCC)

Note: For some SICs, only the emissions of major SCCs have been listed. The totals may therefore differ from those in Table 2.

SIC Name	SIC #	SCC Name	SCC #	Emissions (tonnes)
NOx Industrial Processes				
Cement & Concrete Manufacture	35210	Oil Fired Hot Water Boiler	10300501	0.4
		Rotary Kiln (dry process)	30500606	52
		Wet Scrubber Stack	10200501	0.2
Forestry				
Kraft (Sulphate) Pulping	27110	Wood Prod.\Sulfate Pulp\Recovery Boiler/Evap	30700194	4195
		Wood Prod.\Sulfate Pulp\Lime Kiln	30700196	4033
		Ext. Comb. Boiler Industrial Residual No.6 Oil	10200401	4205
		Ext. Comb. Boiler Ind\Nat. Gas 100+ GJ/hr\B.C.	10200691	414
		Ext. Comb. Boiler Ind\Nat. Gas 10-100 GJ/hr\B.C.	10200692	529
		Ext. Comb. Boiler Ind\Wood/Bark Boiler	10200992	1800
		Ext. Comb. Boiler Ind\Wood/Bark & Low Oil	10200998	136
Sawmills	25120	Ext. Comb. Boiler Ind\Nat. Gas\-10 GJ/hr/B.C.	10200693	116
		Ext. Comb. Boiler Industrial Wood/Bark Waste	10200901	281
		Ext. Comb. Boiler Industrial Wood/Bark Waste	10200904	174
		Ext. Comb. Boiler Industrial Wood/Bark Waste	10200905	5
		Ext. Comb. Boiler Industrial Wood/Bark Waste	10200906	137
		Solid Waste Displ Ind. Incineration Trench Burner	50300106	15
		Solid Waste Industrial\Incinerator\Conical Wood	50300195	2739
		Solid Waste Displ Industrial Open Burning Wood	50300201	2

SIC Name	SIC #	SCC Name	SCC #	Emissions (tonnes)
Mining				
Coal Industry	06300	Fluid Bed Dryer	30501091	1257
		Preparation Plant Heating Boiler	10500102	3
		Camp Refuse Incinerator	50300101	0.1
Oil & Gas Production				
Natural Gas Processing Industry	07110	Ext. Comb. Boiler Ind\Nat. Gas\10-100 GJ/hr/B.C.	10200692	744
		Ext. Comb. Boiler Ind\Nat. Gas\-10 GJ/hr/B.C.	10200693	8
		Int. Comb. Elec. Gen.\Nat. Gas\ Reciprocating\B.C.	20100292 + 20200292	7953
Other Industrial Fuel Combustion	56223	Stationary Source - Residual Oil	0013520	1400
Other Industries				
Industrial Inorganic Chemical Ind.	03711	Chemical Mfg Methanol General Production	30125001	2105
Brewery Products Industry	11310	Natural Gas Fired Boilers	10200691	458
Primary Metals				
Aluminum Production	29510	Al Elect Reduc\Coke Calcining	30300191	2022
		Al Casting\Gas Fired	30300193	20
Petroleum Refining	36100	Catalytic Cracking Fluid Cat. Cracker	30600201	881
		Natural Gas Heaters and Boilers	30600195	125
NOx LOMEI Industrial Point Sources				
Cement & Concrete Manufacture				
Non-Metallic Mineral	35210	GVRD (Non Metallic Mineral)	00055100	4293
Petroleum Refining	36100	Cat. Cracking Fluid Cat. Cracker &	30600201 &	
		Natural Gas Heaters and Boilers	30600195	20

SIC Name	SIC #	SCC Name	SCC #	Emissions (tonnes)
Other Industries	varied			852
Forestry				
Sawmills (Wood Industries)	25120	Wood Industry - Sawmill Production	00057100	613
Paper & Allied	27120	Wood products - Sawmill Operations Not Classified	30700897	605
Chemical Industry				
Industrial Inorganic Chemicals Ind.	03711	Chemical Mfg Miscellaneous Not Classified	30199999	268
NOx Fuel Combustion				
Commercial Fuel Combustion	56222	Stationary Source - Natural Gas Burned	00012100	2039
		Stationary Source - Liquid Petroleum Gas	00012200	104
		Stationary Source - Kerosene Burned	00012300	42
		Stationary Source - Distillate Oil	00012500	264
		Stationary Source - Residual Oil	00012520	263
Electric Power Generation	49110	Stationary Source Electric Power - Misc. Diesel	00014400	2012
		Ext. Comb. Boiler Elec. Gen. - Distillate Oil	10100501	38
		Int. Comb. Elec. Gen. Diesel	20100101	24
		Int. Comb. Elec. Gen. Diesel	20100102	1705
		Int. Comb. Elec. Gen. Natural Gas	20100291	132
	(Burrard Thermal)	Ext. Comb. Boiler Elec. Gen. Natural Gas	20100291	2200
Residential Fuel Combustion	56221	Stationary Source - Residential Natural Gas	00011100	2489
		Stationary Source - Residential Liquid Pet. Gas	00011200	105
		Stationary Source - Residential Kerosene	00011300	93
		Stationary Source - Residential Coal	00011400	12
		Stationary Source - Residential Distillate Oil	00011510	621
		Stationary Source - Residential Residual Oil	00011520	73

SIC Name	SIC #	SCC Name	SCC #	Emissions (tonnes)
NOx Miscellaneous				
Slash Burning	04120	Slash Burning	00033100	9033
NOx Incineration				
Wigwam Burners	04111	Solid Waste Incineration - Wood Waste Disposal	00032100	2100
Industrial Incineration	49992	Solid Waste Incineration - Multiple Chamber	00031300	65
		Solid Waste Incineration - Controlled Air	00031500	72
Municipal Incineration	49990	Solid Waste Gov't\Incineration\Not Classified (Burnaby Incinerator)	50100599	312
NOx Transportation				
Aircraft	45110	Off-Highway Mobile Source - Jet Aircraft	00023110	120
		Off-Highway Mobile Source - Turboprop	00023120	17
		Off-Highway Mobile Source - Piston Engine	00023130	1.4
		Off-Highway Mobile Source - Helicopters	00023140	3
		Off-Highway Mobile Source - Small Piston	00023150	0.7
		Off-Highway Mobile Source - Jet Aircraft Inflight	00023210	2836
		Off-Highway Mobile Source - Piston Inflight	00023240	92
		Off-Highway Mobile Source - Helicopter Inflight	00023240	26
		Off-Highway Mobile Source - Local Aircraft Ems.	00023250	37
Gasoline Powered Automobiles	45890	Gasoline Powered Automobiles	00022100	51475
Heavy - Duty Diesel Vehicles	45604	Heavy - Duty Diesel Vehicles	00021400	45609

SIC Name	SIC #	SCC Name	SCC #	Emissions (tonnes)
Heavy - Duty Gasoline Trucks	45601	Gasoline Powered Vehicles - Heavy Duty Trucks	00021200	4585
Light - Duty Gasoline Trucks	45600	Gasoline Powered Vehicles - Light Duty Trucks	00021100	24742
Light - Duty Diesel Trucks	45603	Diesel Powered Engines - Light Duty Vehicles	00021300	822
Motor Cycles	45891	Gasoline Powered Vehicles - Motor Cycles	00021150	173
Marine	45400	Off-Highway Mobile Source - Motorships Dockside	00025110	1167
		Off-Highway Mobile Source - Gasoline Outboard	00025310	26
Off-Road Use of Gasoline	45894	Non-Highway Use of Gasoline	00022100	2190
Snowmobiles	45892	Gasoline Powered Vehicles - Snowmobiles	00022140	30
Railroads	45310	Off-Highway Mobile Source - Diesel Oil - Railroads	00024100	15618
Other Diesel Vehicles	45602	Diesel Powered Vehicles - Agricultural Vehicles	00022210	2852
		Diesel Powered Vehicles - Construction Vehicles	00022220	4013
		Diesel Powered Vehicles - Mining Vehicles	00022230	8157
		Diesel Powered Vehicles - Manufacturing Vehicles	00022240	12094
		Diesel Powered Vehicles - Forestry Vehicles	00022250	8120
		Diesel Powered Vehicles - Public Administration V.	00022260	7999
		Diesel Powered Vehicles - Pipeline Vehicles	00022270	737

SIC Name	SIC #	SCC Name	SCC #	Emissions (tonnes)
VOC Transportation				
Aircraft	45110	Off-Highway Mobile Source - Jet Aircraft	00023110	108
		Off-Highway Mobile Source - Turboprop	00023120	12
		Off-Highway Mobile Source - Piston Engine	00023130	20
		Off-Highway Mobile Source - Helicopters	00023140	2
		Off-Highway Mobile Source - Small Piston	00023150	7
		Off-Highway Mobile Source - Jet Aircraft Inflight	00023210	20
		Off-Highway Mobile Source - Piston Inflight	00023240	638
		Off-Highway Mobile Source - Helicopter Inflight	00023240	22
		Off-Highway Mobile Source - Local Aircraft Ems.	00023250	581
Gasoline Powered Automobiles	45890	Gasoline Powered Automobiles	00022100	60890
Heavy - Duty Diesel Vehicles	45604	Heavy - Duty Diesel Vehicles	00021400	6229
Heavy - Duty Gasoline Trucks	45601	Gasoline Powered Vehicles - Heavy Duty Trucks	00021200	6885
Light - Duty Gasoline Trucks	45600	Gasoline Powered Vehicles - Light Duty Trucks	00021100	36887
Light - Duty Diesel Trucks	45603	Diesel Powered Engines - Light Duty Vehicles	00021300	193
Motor Cycles	45891	Gasoline Powered Vehicles - Motor Cycles	00021150	743
Marine	45400	Off-Highway Mobile Source - Motorships Dockside	00025110	770
		Off-Highway Mobile Source - Gasoline Outboard	00025310	4033
Off-Road Use of Gasoline	45894	Non-Highway Use of Gasoline	00022100	3503
Snowmobiles	45892	Gasoline Powered Vehicles - Snowmobiles	00022140	1700

SIC Name	SIC #	SCC Name	SCC #	Emissions (tonnes)
Railroads	45310	Off-Highway Mobile Source - Diesel Oil - Railroads	00024100	758
Other Diesel Vehicles	45602	Diesel Powered Vehicles - Agricultural Vehicles	00022210	495
		Diesel Powered Vehicles - Construction Vehicles	00022220	370
		Diesel Powered Vehicles - Mining Vehicles	00022230	631
		Diesel Powered Vehicles - Manufacturing Vehicles	00022240	924
		Diesel Powered Vehicles - Forestry Vehicles	00022250	849
		Diesel Powered Vehicles - Public Administration V.	00022260	549
		Diesel Powered Vehicles - Pipeline Vehicles	00022270	60
Tire & Tube Industry	15111	Tire Wear - 4 Wheeled	00026100	81
		Tire Wear - 8 Wheeled	00026200	22
VOC Miscellaneous				
Painting & Decorating	42751	Application of Surface Coating - Trade, Sales Use	00077000	6961
		Application of Surface Coating - Industrial Use	00078200	7014
Dry Cleaning Plants	97211	Dry Cleaning	00071000	5129
Gasoline Fuel Marketing	51111	Diesel & Gasoline Mkting-Refinery Storage Transfer	00027110	2030
		Diesel & Gasoline Mkting-Filling Vehicle Tank	00027111	859
		Diesel & Gasoline Mkting-Station Storage Transfer	00027130	3247
		Diesel & Gasoline Mkting-Vapour Loss at Stations	00027140	419
		Diesel & Gasoline Mkting-Transfer to Cars	00027150	4800
		Diesel & Gasoline Mkting-Spillage at Station	00027160	279
		Bulk Plant Fixed Roof Working Losses	40400294	160
		Pet. Stg.\Bulk Plant\Standing Losses	40400297	168
		Roof TNK Tank Cars/Trucks Gasoline	40600131	328

SIC Name	SIC #	SCC Name	SCC #	Emissions (tonnes)
General Solvent Use	65321	General Solvent Use	00070000	12003
Slash Burning	04120	Slash Burning	00033100	43944

APPENDIX E

EMISSION FORECASTS FOR NOX/VOC

SCENARIO I:

Emission Forecasts (based on EMPR energy forecasts): NOx/VOC

	EMPR Energy Forecasts (PJ) (1)				Greenhouse Gases Inv.			
Sector	1988	2005	1985 (est)	Forecast % Change (1985-2005)	Actual Em. (kT 1985) NOx	Actual Em. (kT 1985) VOC	Forecast Em. (kT 2005) NOx	Forecast Em. (kT 2005) VOC
TRANSPORTATION								
Gas Vehicles	125.1	134.7	123.4	9.2	83.2	110.7	90.9	120.9
Diesel Vehicles	39.0	60.6	35.2	72.0	90.4	10.2	155.5	17.5
Other (2)	78.4	102.0	74.3	37.0	19.9	7.1	27.3	9.7
SUB-TOTAL					193.5	128.0	273.7	148.1
FUEL COMBUSTION								
Residential	129.8	191.1	119.0	60.7	3.6	4.0	5.8	6.4
Commercial	92.1	129.1	79.7	61.9	2.8	0.2	4.5	0.3
Power Generation	23.5	100.7	9.9	922	5.9	0.3	54.1	2.9
SUB-TOTAL					12.3	4.5	64.4	9.6
INDUSTRIAL PROC. (3)	453.7	618.3	423.0	46.2	47.6	58.9	69.6	86.1

APPENDIX E (Cont'd): EMISSION FORECASTS FOR NOX/VOC

SCENARIO I (Cont'd): *Emission Forecasts (based on EMPR energy forecasts): NOx/VOC*

	EMPR Energy Forecasts (PJ)				Greenhouse Gases Inv.			
Sector	1988	2005	1985 (est)	Forecast % Change (1985-2005)	Actual Em. (kT 1985) NOx	Actual Em. (kT 1985) VOC	Forecast Em. (kT 2005) NOx	Forecast Em. (kT 2005) VOC
INCINERATION/MISC.								
Mun./Ind. Incineration				96.3 (4)	0.5	0.1	1.0	0.2
Wood Waste Incineration				-29.0 (4)	2.1	2.4	1.5	1.7
Slash Burning				-35.4 (4)	9.0	43.9	5.8	28.6
Fuel Marketing				9.2 (5)	-	12.4	-	13.5
Dry Cleaning				45.7 (6)	-	5.1	-	7.4
Solvent Use				45.7 (6)	-	12.0	-	17.5
Surface Coatings				45.7 (6)	-	14.0	-	20.4
SUB-TOTAL					11.6	89.9	8.3	48.6
Total					**265**	**281.3**	**416**	**287.8**

(1) Energy forecast data obtained from B.C. EMPR (1991).

(2) B.C. EMPR energy demand forecast data for aircraft, marine, rail, natural gas end use, electricity end use, and LPG vehicles.

(3) Includes LOMEI point sources.

(4) Growth estimates obtained from B.C. EMPR CO_2 Inventory for B.C. (1988) extrapolated to1985.

(5) Assume growth forecast in fuel marketing is equal to energy demand forecast for gas vehicles.

(6) Growth forecast based on population forecast to 2016 prorated to 2005 (B.C. FIN, 1991).

APPENDIX E (Cont'd)
EMISSION FORECASTS FOR NOX/VOC

SCENARIO II:

Emission Forecasts NOx/VOC Management Plan 90-B: NOx

	NOx/VOC Mgt. Plan		Greenhouse Gases Inv.	
Sector	Actual Em. 1985 (kT)	Forecast Change 1985-2005	Actual Em. 1985 (kT)	Forecast Em. 2005 (kT)
TRANSPORTATION				
Cars	46.6	- 58.4	51.5	21.4
Light-duty trucks				
gas	17.3	- 42.8	24.7	14.2
diesel	0.9	+ 100	0.8	1.6
Heavy-duty trucks				
gas	4.8	- 66.7	4.6	1.5
diesel	48.2	- 40.5	45.6	27.1
Off-road diesel				
construction	4.0	+ 5	4.0	4.2
agriculture	2.9	+151.7	2.9	7.2
railroads	16.8	- 20.2	15.6	12.5
other	37.2	+ 18.8	37.1 (1)	44.1
Other	6.7	+ 37.3	6.7 (2)	9.2
SUB-TOTAL	185.4		193.5	141.4
FUEL COMBUSTION				
Residential	3.6	- 8.3	3.6	3.3
Commercial	2.7	+ 7.4	2.8	3.0
Power Generation	3.7	- 67.6	5.9 (3)	1.9
SUB-TOTAL	10.0		12.3	8.2
INDUSTRIAL PROC.(4)				
Industrial Processes	10.7	+ 56.1	45.0	70.2
Other Ind. Fuel Comb	35.2	+ 36.1	2.6	3.5
SUB-TOTAL	45.9		47.6	73.7
INCINERATION/MISC.	11.3	+ 21.2	11.6 (5)	14.03
Total	**252.6**		**265**	**223.3**

(1) Vehicles for mining, manufacturing, forestry, public administration, and pipeline vehicles.

(2) Aircraft, motorcycles, marine vehicles, off road use of gasoline excluding everything under (1), and snowmobiles.

(3) Electric power generation including Burrard Thermal.

(4) Industrial processes and LOMEI point sources. Includes other industrial fuel combustion.

(5) Slash burning (Misc.) and Incineration (wigwam burners, industrial incineration, municipal incineration and Burnaby Incinerator).

SCENARIO II (Cont'd):

Emission Forecasts NOx/VOC Management Plan 90-B: VOC

Sector	NOx/VOC Mgt. Plan Actual Em. 1985 (kT)	NOx/VOC Mgt. Plan Forecast Change 1985-2005	Greenhouse Gases Inv. Actual Em. 1985 (kT)	Greenhouse Gases Inv. Forecast Em. 2005 (kT)
TRANSPORTATION				
Cars	58.3	- 39.1	60.9	37.1
Light-duty trucks				
gas	26.3	- 46	36.9	19.9
diesel	0.2	+ 200	0.2	0.6
Heavy-duty trucks				
gas	6.9	- 82.6	6.9	1.2
diesel	5.2	- 5.8	6.2	5.9
Off-road gasoline	5.2	+ 9.6	3.5	3.8
Other	11.7	+45.3	13.4	19.5
SUB-TOTAL	113.8		128	88
FUEL COMBUSTION				
Fuelwood (Residential)	3.8	+ 31.6	3.8	5.1
Residential/Commerc.	0.3	+- 0.0	0.3	0.3
Power Generation	0.3	+- 0.0	0.3	0.3
SUB-TOTAL	4.4		4.4	5.7
INDUSTRIAL PROC. (1)				
Industrial Processes	14.7	+ 52.4	57.5	87.6
Other Ind. Fuel Comb.	42.7	+ 30.7	1.4	1.8
SUB-TOTAL	57.4		58.9	89.4
INCINERATION/MISC.				
Surface Coatings	21.5	+ 17.2	14.0	16.4
Fuel Marketing	12.4	- 8.1	12.3	11.4
Dry Cleaning	1.6	+ 12.5	5.1	5.8
Solvent Use	30.3	+ 13.2	12.0	13.6
Slash burning	43.9	+ 30.8	43.9	57.5
Other (2)	9.1	+ 26.4	-	-
SUB-TOTAL	118.8		87.3	94.7
Total (3)	**294.4**		**278.6**	**277.8**

(1) Industrial processes and LOMEI point sources. Includes other industrial fuel combustion.

(2) Unclear what Misc. (Other) in NOx/VOC Mgt Plan accounts for.

(3) Excluding Misc. (Other).

SCENARIO III:

Emission Forecasts NOx/VOC Management Plan - Post-Plan: NOx

Sector	NOx/VOC Mgt. Plan Reduction 90-B to post plan (%)	Greenhouse Gases Inv. Act Em. 1985 (kT)	90-B Em. forecast (kT)	Post plan Em. forecast (kT)
TRANSPORTATION (1)				
LDVs	29.3	77.0	37.2	26.3
HDVs	10.2	50.2	28.6	25.7
Off road diesel	1.0	59.6	68.0	67.3
SUB-TOTAL		186.8	133.8	119.3
FUEL COMBUSTION				
Comm./Ind. fuel comb.	18.3	2.8	3.0 (2)	2.5
Residential fuel comb.	9.1	3.6	3.3	3.0
Elect. power gen.	83.3	5.9	1.9	0.3
SUB-TOTAL		12.3	8.2	5.8
INDUSTRIAL PROCESSES	6.0	47.6	73.7	69.3
Total		**246.7**	**215.7**	**194.4**

(1) LDVs - assume to include all cars and light duty trucks; HDVs assume to include all heavy duty gas and diesel trucks; Off-road diesel (see Plan 90-B above).

(2) Only commercial fuel combustion. However, for the post plan emission forecast, the combined reduction estimate for commercial and industrial fuel combustion was applied.

Emission Forecasts NOx/VOC Management Plan - Post-Plan: VOC

Category	NOx/VOC Mgt. Plan Reduction 90-B to post plan (%)	Greenhouse Gases Inv. Act Em. (1985) (kT)	90-B Em. forecast (kT)	Post plan Em. forecast (kT)
TRANSPORTATION				
LDVs	23.7	98.0	57.6	44.0
IND. PROCESS/COMB.	10.3	63.3	95.1	85.3
MISCELLANEOUS				
Vol. Liq. Storage (1)	18.4	12.3	11.4	9.3
Paints/coatings	35.7	14.0	16.4	10.5
Other Solvents Use (2)	21.3	17.1	19.4	15.3
SUB-TOTAL		43.4	47.2	35.1
Total		**204.7**	**199.9**	**164.4**

(1) Assume equivalent to fuel marketing.

(2) Assumed to include the categories dry cleaning and solvent use

APPENDIX F: B.C. EMPR ENERGY DEMAND FORECAST DATA

COMMERCIAL SECTOR ENERGY DEMAND (PJ)

YEAR	DELCCON	DNGSCON	DRPPCON	DTOTCON	YEAR
1990	42.62 (46.3)	35.84 (38.9)	13.61 (14.8)	92.08	1990
1991	42.92	38.99	12.29	94.22	1991
1992	43.74	41.62	11.64	97.01	1992
1993	44.88	43.47	11.66	99.99	1993
1994	45.74	44.87	12.13	102.75	1994
1995	47.15	45.40	12.77	105.33	1995
1996	48.73	46.71	12.26	107.70	1996
1997	50.48	48.01	11.73	110.19	1997
1998	52.03	49.30	11.12	112.46	1998
1999	53.48	49.71	11.37	114.56	1999
2000	55.12	50.35	11.56	117.04	2000
2001	56.70	51.43	11.23	119.37	2001
2002	58.23	52.35	10.86	121.66	2002
2003	59.80	53.79	10.50	124.11	2003
2004	61.22	55.16	10.18	126.57	2004
2005	62.54	56.68	9.92	129.12	2005
2006	63.90	56.91	11.13	131.95	2006
2007	65.22	58.31	11.00	134.54	2007
2008	66.50	59.80	10.86	137.16	2008
2009	67.81	61.32	10.69	139.83	2009
2010	69.17	62.88	10.49	142.55	2010

Total (Commercial)
Refined Petroleum Products
Natural Gas
Electricity

MNEMONIC	TITLE	SECTO	FUEL	DESCRIPT	UNITS	LAST_A	Y1988	Y1989	Y2005	Y2010
INDUSTRY & MINING										
	CHEMICALS									
DHFOCHE		CHE	HFO	SECONDARY REQTS; HEAVY FUEL OIL; CHEMICALS	PJ	1985	0.61427	0.63989	0.45068	0.43958
DLFOCHE		CHE	LFO	SECONDARY REQTS; LIGHT FUEL OIL; CHEMICALS	PJ	1985	0.03772	0.03703	0.02608	0.02544
DELCCHE	Elec:Chemicals	CHE	ELC	SECONDARY REQTS; ELECTRICITY; CHEMICALS	PJ	1985	4.00000	4.64424	6.37688	6.45882
DNGSCHE	Ngs:Chemicals	CHE	NGS	SECONDARY REQTS; NATURAL GAS; CHEMICALS	PJ	1985	4.30762	4.55348	4.53131	4.51711
	SUB-TOTAL						8.95961	9.87464	11.38495	11.44095
	MINING									
DNGSMIN	Ngs:Mining	MIN	NGS	SECONDARY REQTS; NATURAL GAS; MINING	PJ	1985	6.87541	5.41252	7.82489	8.48297
DDFOMINSE		MIN	DFO	SECONDARY REQTS; DIESEL FUEL; MINING	PJ	1988	10.35780	7.55390	5.02396	5.03051
DELCMIN		MIN	ELC	SECONDARY REQTS; ELECTRICITY; MINING	PJ	1985	10.47270	11.10120	11.46510	10.20870
DLPGMIN		MIN	LPG	SECONDARY REQTS; LPGs; MINING	PJ	1985	0.36972	0.27719	0.19371	0.19392
	SUB-TOTAL									
DLPGNMT		NMT	LPG	SECONDARY REQTS; LPGs; NON-METALLIC	PJ	1985	0.01226	0.01220	0.01393	0.01445
DBGSNMT	Biogas:Cement	NMT	BGS	BIOGAS EXTRACTED FROM RICHMOND MUNICIPAL D	PJ	1988	0.15696	0.15653	0.19094	0.20432
DCACNMT	Coal:Cement	NMT	CAC	SECONDARY REQTS; COKE & COAL; NON-METALLIC	PJ	1985	0.94508	0.94249	1.14965	1.23023
DNGSNMT	Ngs:Cement	NMT	NGS	SECONDARY REQTS; NATURAL GAS; NON-METALLIC	PJ	1985	2.71820	2.71252	3.37237	3.63866
DELCNMT	Elec:Cement	NMT	ELC	SECONDARY REQTS; ELECTRICITY; NON-METALLIC	PJ	1985	0.66400	0.57091	0.72960	0.78798
DPCKNMT		NMT	PCK	SECONDARY REQTS; PETROLEUM COKE; NON-METALL	PJ	1988	0.71000	0.70652	0.80649	0.83702
DDFONMT		NMT	DFO	SECONDARY REQTS; DIESEL FUEL; NON-METALLIC	PJ	1985	0.09334	0.09288	0.10602	0.11004
	SUB-TOTAL						5.29984	5.19405	6.369	6.8227
	REFINING									
DCACSUP	Coal:Mining Own Use	REF	CAC	PRODUCER REQTS; COKE & COAL	PJ	1989	4.01300	5.11088	6.37923	6.73074
DNGSREF	Ngs:Refineries	REF	NGS	SECONDARY REQTS; NATURAL GAS; REFINERY	PJ	1988	1.24537	0.47942	0.55783	0.43598
DMOGSUP		REF	MOG	PRODUCER REQTS; MOTOR GASOLINE	PJ	1989	0.00700	0.22466	0.11776	0.11247
DSGSSUP		REF	SGS	PRODUCER REQTS; STILL GAS	PJ	1989	17.25100	17.25110	11.84630	11.01420
DDFOSUP		REF	DFO	PRODUCER REQTS; DIESEL FUEL	PJ	1989	0.16000	0.47440	0.39088	0.37343
	SUB-TOTAL						22.67637	23.54046	19.292	18.66682
	PRIMARY METALS									
DELCPMT	Elec:Primary Metals	PMT	ELC	SECONDARY REQTS; ELECTRICITY; PRIMARY METALS	PJ	1985	0.69000	0.59217	0.75582	0.75075
DDFOPMT		PMT	DFO	SECONDARY REQTS; DIESEL FUEL; PRIMARY METALS	PJ	1985	0.10090	0.09526	0.03185	-0.01687
DLFOPMT		PMT	LFO	SECONDARY REQTS; LIGHT FUEL OIL; PRIMARY META	PJ	1985	0.05697	0.05056	0.01751	-0.00927
DHFOPMT		PMT	HFO	SECONDARY REQTS; HEAVY FUEL OIL; PRIMARY MET	PJ	1985	0.04129	0.04305	0.01359	-0.00720
DNGSPMT	Ngs:Primary Metals	PMT	NGS	SECONDARY REQTS; NATURAL GAS; PRIMARY METAL	PJ	1985	2.14000	2.02843	2.30691	2.50364
	SUB-TOTAL						3.02916	2.80947	3.12568	3.22105
DHFOXIN		XIN	HFO	SECONDARY REQTS; HEAVY FUEL OIL; OTHER INDUST	PJ	1988	-1.53488	0.09589	0.09589	0.09589
DDFOXIN		XIN	DFO	SECONDARY REQTS; DIESEL FUEL; OTHER INDUSTRIA	PJ	1988	4.35878	12.12810	12.12810	12.12810
DLFOXIN		XIN	LFO	SECONDARY REQTS; LIGHT FUEL OIL; OTHER INDUST	PJ	1988	1.20894	1.37000	1.37000	1.37000
DNGSXINSE	Ngs:Other Ind	XIN	NGS	SECONDARY REQTS; NATURAL GAS; OTHER IND	PJ	1988	12.08380	5.42000	6.87790	7.40945
DLPGXIN		XIN	LPG	SECONDARY REQTS; LPGs; OTHER INDUSTRIAL	PJ	1988	-0.32027	-0.76874	-0.76874	-0.76874
	SUB-TOTAL						15.79637	18.24525	19.70315	20.2347
DNGSXMA	Ngs:Other Manf	XMA	NGS	SECONDARY REQTS; NATURAL GAS; OTHER MANUFA	PJ	1985	16.76250	16.60850	29.37030	34.85090
DELCXMA	Elec:Other Manf	XMA	ELC	SECONDARY REQTS; ELECTRICITY; OTHER MANUFAC	PJ	1985	6.74653	6.69014	16.35380	19.64100
DLPGXMA		XMA	LPG	SECONDARY REQTS; LPGs; OTHER MANUFACTURING	PJ	1985	0.26943	0.27853	0.43950	0.48494
DDFOXMA		XMA	DFO	SECONDARY REQTS; DIESEL FUEL; OTHER MANUFACT	PJ	1985	0.71986	0.74417	1.17424	1.29565
DLFOXMA		XMA	LFO	SECONDARY REQTS; LIGHT FUEL OIL; OTHER MANUF	PJ	1985	0.23272	0.24058	0.19016	0.22941
DHFOXMA		XMA	HFO	SECONDARY REQTS; HEAVY FUEL OIL; OTHER MANUF	PJ	1985	0.16776	0.17343	0.09509	0.12338
	SUB-TOTAL						24.8988	24.73535	47.62309	56.62528
	TOTAL						64.91323	65.66242	87.21969	96.20198

MNEMONIC	TITLE	SECTO	FUEL	DESCRIPT	UNITS	LAST_A	Y1988	Y1989	Y2005	Y2010
DLGRNON		NON	LGR	SECONDARY REQTS; LUBES & GREASES; NON-ENERGY	PJ	1988	4.42100	4.80970	4.97762	5.06198
DASPNON		NON	ASP	SECONDARY REQTS; ASPHALT; CONVERTED @ 44.46TJ	PJ	1988	7.86500	7.97169	8.28447	8.46040
DPCKNON		NON	PCK	SECONDARY REQTS; PETROLEUM COKE; NON-ENERGY	PJ	1989	3.14000	3.64479	4.30480	4.30480
DOTHNON		NON	OTH	SECONDARY REQTS; OTHER NON-ENERGY	PJ	1988	2.58000	4.11000	5.36838	5.44792
	SUB-TOTAL						18.006	20.53618	22.93527	23.2751
	PULP & PAPER									
DELCPAPSE	Elec:Pulp&Paper	PAP	ELC	ELECTRICITY; PULP&PAPER	PJ	1988	37.95790	40.57860	75.65340	80.70320
DDFOPAPSE	DFO:Pulp&Paper	PAP	DFO	SECONDARY REQTS; DIESEL FUEL; PULP&PAPER	PJ	1988	0.46586	0.50275	0.63117	0.66735
DOTHPAP	Biogas&Tall Oil:P&P	PAP	OTH	SECONDARY REQTS; OTHER FUEL; PULP&PAPER	PJ	0	0.75000	0.70965	1.44624	1.55714
GNGSPAP		PAP	NGS	USED TO GENERATE ELEC; NATURAL GAS; PULP&PAP	PJ	1989	3.27739	3.62456	5.97881	6.86152
DLIQPAPSE	Liq:Pulp&Paper	PAP	LIQ	SECONDARY REQTS; PULPING LIQUORS; PULP&PAPER	PJ	1986	131.18500	132.42100	141.67900	143.90700
GHFOPAP		PAP	HFO	USED TO GENERATE ELEC; HEAVY FUEL OIL; PULP&P	PJ	1989	2.89301	3.11588	4.19993	4.40511
DHFOPAPSE	HFO:Pulp&Paper	PAP	HFO	SECONDARY REQTS; HEAVY FUEL OIL; PULP&PAPER	PJ	1986	20.09430	23.38860	18.61820	19.97130
DLPGPAPSE	LPGs:Pulp&Paper	PAP	LPG	SECONDARY REQTS; LPGs; PULP&PAPER	PJ	1988	0.30711	0.32647	0.38572	0.40704
GLIQPAP	Liq:Converted to Elc	PAP	LIQ	USED TO GENERATE ELEC; PULPING LIQOUR;PULP&PA	PJ	1986	5.48015	6.11650	6.78823	6.92572
DNGSPAPSE	Ngs:Pulp&Paper	PAP	NGS	SECONDARY REQTS; NATURAL GAS; PULP&PAPER	PJ	1986	23.51890	23.41220	45.15870	47.33160
DCACPAP2	Coal:Pulp&Paper	PAP	CAC	SECONDARY REQTS; COKE & COAL; PULP&PAPER; RE	PJ	1988	0.24612	0.09376	0.23344	0.23670
	SUB-TOTAL						226.17574	234.28997	300.77284	312.97368
DNGSPCM	Ngs:Petrochemicals	PCM	NGS	FEEDSTOCK REQTS; NATURAL GAS	PJ	1988	18.66200	24.09800	25.13490	25.13490
	SUB-TOTAL						18.662	24.098	25.1349	25.1349
	REDIDENTIAL/AGR.									
DLFORES	LFO:Residential	RES	LFO	SECONDARY REQTS; LIGHT FUEL OIL; AGRICULTURAL	PJ	1989	11.69400	11.55110	3.42540	2.90353
DLPGRES	LPGs:Residential	RES	LPG	SECONDARY REQTS; LPGs; RESIDENTIAL	PJ	1989	1.36500	1.33770	0.55780	0.46465
DCACRES	Coal:Residential	RES	CAC	SECONDARY REQTS; COKE & COAL; RESIDENTIAL	PJ	1989	0.00600	0.00588	0.00426	0.00385
DELCRES	Elec:Residential	RES	ELC	SECONDARY REQTS; ELECTRICITY; RESIDENTIAL	PJ	1989	43.35300	44.80680	63.97590	68.29650
DNGSRES	Ngs:Residential	RES	NGS	SECONDARY REQTS; NATURAL GAS; RESIDENTIAL	PJ	1989	71.78000	78.34070	119.34300	129.25300
DDFORES	DFO:Residential	RES	DFO	SECONDARY REQTS; DIESEL FUEL; AGRICULTURE	PJ	1989	1.59900	3.28725	3.83746	4.01434
	SUB-TOTAL						129.797	139.32943	191.14382	204.93587
	PRODUCER REQUIREMENTS									
	POWER GENERATION									
DPCKSUP		SUP	PCK	PRODUCER REQTS; PETROLEUM COKE	PJ	1989	1.90200	1.98949	1.89706	1.89709
DHFOSUP		SUP	HFO	PRODUCER REQTS; HEAVY FUEL OIL	PJ	1989	0.25400	0.34212	0.39366	0.37616
DLFOSUP		SUP	LFO	PRODUCER REQTS; LIGHT FUEL OIL	PJ	1989	0.00500	0.02081	0.01400	0.01338
DELCSUP	Elec:Losses	SUP	ELC	PRODUCER REQTS; ELECTRICITY	PJ	1989	17.51900	18.19300	28.19120	30.60770
GDFOTOT	DFO:Converted to Elc	SUP	DFO	USED TO GENERATE ELEC; DIESEL FUEL; TOTAL	PJ	1989	2.52000	2.54662	3.03488	3.21452
DNENSUP		SUP	NEN	PRODUCER REQTS; NON-ENERGY PRODUCTS	PJ	1989	0.07500	0.54625	0.24488	0.24488
GELCUTL	Elec:From Utl(Thermal)	SUP	ELC	THERMAL GENERATION; ELEC; UTILITIES	PJ	1990	0.30000	15.10000	26.65280	26.70540
DHOGTOTSE	Hog:Secondary Reqts	SUP	HOG	SECONDARY REQTS; HOG FUEL; TOTAL	PJ	1986	67.73400	68.71170	82.35820	84.33480
DNGSPIP	Ngs:Pipelines&Losses	SUP	NGS	PIPELINE USE; NATURAL GAS	PJ	1989	14.68600	17.47630	29.75980	32.24700
GNGSWKPL		SUP	NGS	USED TO GENERATE ELEC; NATURAL GAS; WKPL REQ	PJ	0	0.00000	0.00000	6.62256	6.62256
GNGSBCH	Ngs:To Elc by Utl	SUP	NGS	USED TO GENERATE ELEC; NATURAL GAS; BC HYDRO	PJ	1990	0.89900	44.03900	40.25800	40.25800
	SUB-TOTAL						105.894	168.96529	219.42704	226.52149
DLPGSUP	RPPs:Ngs Plant Own Use	NGS	LPG	PRODUCER REQTS; LPGs	PJ	1989	0.31800	0.31275	0.26470	0.25038
	SUB-TOTAL						0.318	0.31275	0.2647	0.25038
	TOTAL						106.212	169.27804	219.69174	226.77187

MNEMONIC	TITLE	SECTO	FUEL	DESCRIPT	UNITS	LAST_A	Y1988	Y1989	Y2005	Y2010
TRANSPORTAION										
	AIR									
DAVGAIR	Air:Aviation Gasoline	AIR	AVG	SECONDARY REQTS; AVIATION GASOLINE; AIR	PJ	1989	1.16900	1.24800	1.75564	1.98635
DAVTAIR	Air:Jet Fuel	AIR	AVT	SECONDARY REQTS; AVIATION TURBO; AIR	PJ	1989	29.41500	33.38790	45.38440	52.30220
	SUB-TOTAL						30.584	34.6359	47.14004	54.28855
	ROAD									
DDFOROD	Road:DFO	ROD	DFO	SECONDARY REQTS; DIESEL FUEL; ROAD	PJ	1989	39.02200	44.40000	60.56330	64.25930
DMOGROD	Road:Gasoline	ROD	MOG	SECONDARY REQTS; MOTOR GASOLINE; ROAD	PJ	1989	125.07200	129.30200	134.74500	136.69100
DLPGROD	Road:LPGs	ROD	LPG	SECONDARY REQTS; LPGs; ROAD TRANSPORT	PJ	1989	5.05200	5.12500	6.29559	6.56752
	SUB-TOTAL						169.146	178.827	201.60389	207.51782
	RAIL									
DDFORAL	Rail:DFO	RAL	DFO	SECONDARY REQTS; DIESEL FUEL; RAIL	PJ	1989	12.52200	12.92030	13.71210	14.15230
	SUB-TOTAL						12.522	12.9203	13.7121	14.1523
	MARINE									
DDFOMAR	Marine:DFO	MAR	DFO	SECONDARY REQTS; DIESEL FUEL; MARINE	PJ	1989	13.32000	13.65140	17.76520	18.21110
DHFOMAR	Marine:HFO	MAR	HFO	SECONDARY REQTS; HEAVY FUEL OIL; MARINE	PJ	1989	15.74000	16.69740	21.39750	23.05120
	SUB-TOTAL						29.06	30.3488	39.1627	41.2623
DELCTRN	Elec:Transport	TRN	ELC	END USE; ELECTRICITY; TRANSPORTATION; TOTAL	PJ	1988	0.36128	0.32224	0.39051	0.41109
DNGSTRN	Ngs:Transport	TRN	NGS	END USE; NATURAL GAS; TRANSPORTATION; TOTAL	PJ	1986	0.85900	0.92682	1.57537	1.70147
	SUB-TOTAL						1.22028	1.24906	1.96588	2.11256
	TOTAL						242.53228	257.98106	303.58461	319.33353

MNEMONIC	TITLE	SECTO	FUEL	DESCRIPT	UNITS	LAST_A	Y1988	Y1989	Y2005	Y2010
	WOOD PRODUCTS									
DNGSWOD	Ngs:Wood	WOD	NGS	SECONDARY REQTS; NATURAL GAS; WOOD PRODUCT	PJ	1985	13.90640	14.05180	15.22400	15.23460
DLFOWOD		WOD	LFO	SECONDARY REQTS; LIGHT FUEL OIL; WOOD PRODUC	PJ	1985	0.12743	0.09499	0.02469	0.01679
DLPGWOD		WOD	LPG	SECONDARY REQTS; LPGs; WOOD PRODUCTS	PJ	1985	0.75139	0.60082	0.14977	0.10184
DDFOWOD		WOD	DFO	SECONDARY REQTS; DIESEL FUEL; WOOD PRODUCTS	PJ	1988	2.00000	1.83971	0.42941	0.29197
DELCWOD	Elec:Wood	WOD	ELC	SECONDARY REQTS; ELECTRICITY; WOOD PRODUCTS	PJ	1985	11.27000	10.92240	12.18950	12.15290
	SUB-TOTAL						28.05522	27.50972	28.01737	27.7981
GELCIND	Elec:From Ind(Thermal)	IND	ELC	THERMAL GENERATION; ELEC; INDUSTRIAL	PJ	1988	9.65455	9.82669	19.12230	20.31900
	SUB-TOTAL									
GHOGTOT	Hog:Converted to Elc				PJ		2.98095	3.31164	13.57420	13.67880
DCACXIN	Coal:Other Ind		CAC	SECONDARY REQTS; COKE & COAL; OTHER IND	PJ	1988	2.53534	2.53578	2.53578	2.53578

APPENDIX G

Summaries of Relevant Air Quality Management Studies

Section 5.2 of the main report summarized a number of key comprehensive air quality management plans for other jurisdictions. In this appendix, other relevant studies are discussed. These studies include local management plans (e.g., GVRD, City of Vancouver) as well as sector-specific investigations.

The GVRD Air Management Plan -- Stage I

The purpose of the GVRD Air Management Plan is to ensure that current and future industrial, commercial, and residential activities in the GVRD take place in a manner that avoids degradation of air quality and will meet current and future air quality objectives and standards. Stage I addresses and evaluates the available emission inventory information, assesses air quality trends and current quality, identifies issues and concerns, and provides recommendations for emission control strategies and completion of the further stages of the Plan (defining resources required, cost-benefit assessment of control options, and selection of control methods).

Key conclusions and recommendations related to NO_x and VOC are:

- the 1985 GVRD emissions inventory should be updated, and improved every five years;
- the B.C. Ministry of the Environment and Environment Canada should be encouraged to implement an advanced photochemical model (the Urban Airshed Model) for use cooperatively with the GVRD;
- expanded monitoring of VOCs should be implemented year-round at regional stations;
- woodstove emissions and open burning should be assessed regarding air quality and visibility and possible control measures should be investigated;
- the existing air quality episode management plan should be expanded and include definitions of possible control actions;
- strategies for controlling obvious sources of VOC emissions should be implemented based on available information. These measures include implementing a vehicle inspection and maintenance program;
- air management planning and transportation planning within the GVRD should be integrated.

Specific VOC control options using known technology were identified:

- Motor vehicles:
  - I/M program
  - Lower gasoline RVP
  - Stricter emissions standards or fuel efficiency
  - On-board emissions controls
  - Alternative fuels

- Transportation systems:
  - Public transit improvements
  - Traffic management (e.g., increased occupancy)
  - Growth and land use management
  - Vehicle use management
  - Stricter emissions standards for air, rail, water

- Petroleum production:
  - Gas transfer emissions
  - Waste water emissions
  - Process emissions
  - Product storage emissions
  - I/M program for fugitive emissions

- Surface coatings and solvents:
  - Substitutes for architectural and other coatings
  - Substitutes and controls for clean up and degreasing
  - Control in dry cleaning and printing
  - Substitutes for consumer products

- General:
  - Waste recycling
  - Energy conservation
  - Energy pricing and subsidy incentives

City of Vancouver Task Force on Atmospheric Change

The City of Vancouver Task Force on Atmospheric Change recommendations are related to three targets:

- Phase out of ozone-depleting chemicals within the City by the year 1995;
- Immediate reduction of sulphur dioxide and methane emissions;
- 20% reduction of 1988 CO_2 levels by 2005, and reduction of "related atmospheric pollutants" to federally acceptable levels.

The latter objective includes measures that will affect NO_x and VOC. Some of the means used to reduce these pollutants are to reduce the number of automobile trips in the City and region, increase opportunities for non-auto travel, and reduce use of gasoline and diesel fuel in conventional buses.

autos, and trucks.

Specific recommendations related to transportation and traffic management are:

- traffic management (trip reduction) by-law that specifies responsibilities of the City, employers, employment complexes, and developers for reasonable efforts in implementing trip reduction and transportation management projects (e.g., require employers of 25 or more to achieve a participation rate of 50% of employees or more in commuting alternatives or alternative work hours);
- parking to favour high-occupancy vehicles (preferential rates, etc.);
- make bicycling a better alternative (require parking, protected routes, etc.);
- short-term emission reduction measures (restrictions of occupancy on certain streets and hours);
- road pricing to fund and improve public transit (program of fees and permits to encourage high occupancy; improved transit, alternative bus fuels, etc.);
- encourage telecommuting as an alternative;
- monitor emissions and transportation subsidies.

There are also land use planning measures mainly related to increasing residential density close to work areas, revising zoning to allow more mix of residential and work areas, etc. with the aim of reducing commuting trips and lengths.

City Council has agreed in principle to set fleet fuel efficiency standards to very low levels (4.7 litres/100 km; or the California Air Resources Board standard). The traffic management by-law was approved, as were many of the other transportation and land use recommendations, either outright or in principle, often with requirements for further study by City officials.

GVRD Vehicle Inspection and Maintenance (I/M) Program

In October of 1989 a Task Force recommended that the various government agencies establish agreement on their respective roles in any I/M program. Such a program was seen to be a cost-effective means of ensuring that vehicles continue to meet federal emissions standards. (Studies have shown that many vehicles do not attain these standards as they age.) An I/M program is estimated to achieve annual reductions of 94,100 tonnes of CO (30% of total vehicle emissions), 6,400 tonnes of hydrocarbons (15% of total vehicle emissions), and 800 tonnes of NO_x (5% of total vehicle emissions).

Study of programs in other jurisdictions suggests that the average test fee would be about $15 per year, and the average cost to owners of associated repairs would be approximately $50, representing a cost of about $465 per tonne ($NO_x/CO_2$ equivalent) reduced. Some of the owner cost would be made up through better fuel efficiency. California results suggest cost per ton of VOC and NO_x to be about $1.35 per ton.

A centralized system (central government facilities) is strongly recommended as being far more effective than a decentralized one (local garages do the tests after operator training). Many specific program designs and standards are discussed.

Vancouver Oxidants Study: Control Technology and Options for VOC Emissions from Gasoline Marketing

Various specific technical solutions are discussed for control of VOC from:

- gasoline storage;
- bulk transfer of gasoline;
- motor vehicle refuelling;
- volatility of gasoline due to high Reid Vapour Pressure (RVP), especially in summer months; and
- other toxic emissions.

The report goes into great detail about techniques associated with various types of storage tank, transfer method, etc., and various scenarios are proposed. The most important sources of VOC emissions were found to be fixed roof tanks, bulk loading of trucks at terminals, service stations, and bulk plant deliveries.

Cost effectiveness was estimated to be:

Measure	Annual reduction (tonnes)	$/tonne VOC
Fixed roof tanks	347	(110)
Truck terminals	1,051	80
Bulk plants	57	190
Service stations:		
- Deliveries	1,421	340
- Refuelling	1,057	4,000

Control of VOC emissions from barges and ships could not be costed due to lack of data.

GVRD Fleet Emission Reduction Study

The purpose of this report was to recommend options for reducing emissions from the GVRD and member municipality vehicle fleets.

It was recommended that the GVRD develop a 5-year plan to set the following objectives:

- Reduce vehicle emissions, recognizing the importance of HC and NO_x on ozone.
- Reduce greenhouse gases by maximizing fuel efficiency of fleet vehicles, and by promoting car pooling, good driving habits, and use of public transportation.
- Set limits on total fleet exhaust and evaporative emissions per year.

- Minimize emissions from off-road machinery and from vehicles using auxiliary equipment.

Strategies include:

- Purchasing vehicles with maximum fuel efficiency, and especially considering emission characteristics during purchase. Energy-consuming options such as air conditioners and high performance engines would be avoided. It was recognized that different fleets had different operating requirements, preferred fuel types, etc., and that emissions targets, rather than specific technologies, should be agreed upon by the various fleet managers.

- Promoting driver focus on fuel economy and setting up a fleet fuel consumption database. This database would also include information on mileage driven, emission specifications, and emission test results for fleet vehicles.

- Reducing the number of non-essential journeys.

- Establishing emission control maintenance and repair procedures, as well as measures to minimize evaporative losses. The I/M system would include vehicle inspection every six months.

- Measuring emissions from fleet vehicles using the proposed provincial system.
- Purchasing optimum gas and diesel fuel formulations based on Environment Canada test data.

- Maintaining a "watching brief" on alternative fuels. (It was thought that the tradeoffs involved in use of these fuels needed further study.)

- Rigorously overhauling used fleet vehicles prior to sale to the public, ensuring a low emissions level.

The estimated impact of these measures are:

- If all GVRD vehicles met new vehicle emission standards, annual HC production would be reduced to about 42% of present fleet levels, NO_x would increase by 11%, and CO would fall to 72% of current fleet levels.

- If all fleet vehicles met proposed 1995 California standards, annual HC production would be about 22% of current levels, NO_x would fall to 58% of the present level, and CO to 37% of current levels.

It was also suggested that the GVRD promote early acceptance of the entire 1995 California Emissions Standards.

No costs were discussed.

Ontario: Reduction of energy use and emissions in Ontario's transportation sector

A 1991 report for the Ontario ministries of energy, environment, and transportation considered opportunities to reduce emissions and energy use in the transportation sector. Emissions created by vehicle use were taken into account, but emissions from energy production and distribution were not considered, nor were direct emission control technologies. In addition, because of existing commitments to reduce "conventional automotive pollutants", the study concentrated only on opportunities to reduce CO_2 emissions through increased energy use efficiency. Thus the measures identified do not include explicit consideration of NO_x and VOC, although reductions of these pollutants were calculated.

Eight types of energy saving measures are discussed:

- fuel efficiency achieved through standards
- increased use of transit
- economic instruments, including "carbon taxes" and "gas guzzler" taxes
- land use planning changes to reduce the need for transportation
- traffic management measures to reduce congestion and speed up traffic flow
- vehicle inspection and maintenance programs
- incentives for substituting communications for transportation
- regulatory restrictions of travel demand

The potential contribution to energy or emission reductions of alternative fuels and bicycling were assessed, but the potential was found to be very small.

Measures are categorized into regulatory, economic, and mixed strategies for meeting four scenarios with different levels of energy and emission reductions. Various types of costs and benefits are discussed for the measures and impact on emissions of CO_2, CO, SO_2, NO_x, VOC and particulates estimated. The report represents a comprehensive examination of emission control measures for Ontario's transportation sector, although discussion of non-monetary barriers to implementation are not considered in detail.

APPENDIX H

ALTERNATIVE FUELS

Alternative fuels have frequently been cited as one method to improve urban air quality. In this appendix a brief overview of the literature is presented. The alternatives considered are compressed natural gas, propane, alcohols (mainly methanol because of ease of production), liquid petroleum gas, and electricity. Each is discussed below.

Fuel Characteristics

Compressed natural gas (CNG): CNG vehicles can be fuelled from either a CNG equipped service station or from a home compressor using the existing CNG supply for home heating. CNG vehicles have several advantages compared to gasoline vehicles, including a lower likelihood of burning or exploding following a crash, the possibility of lower operating costs (sources disagree somewhat about this; it may be true only for high-mileage vehicles), and lower emissions. It is essentially a non-toxic fuel.

Disadvantages include: natural gas must be compressed for vehicle use -- the costs of compression facilities are about $25,000 for a commercial service station and about $2,500 for a home compressor (which will also require yearly servicing); high vehicle conversion costs (about $1,500 - 2,000 per vehicle); about 10% less power than gas engines vehicles for converted vehicles; and low range (only about one third that from the same amount of gasoline). The lower cost per litre of fuel would, however, eventually reduce operating costs. Diesel vehicles would require a prohibitively large fuel tank weighing about 1,500 lbs. to give range equivalent to a 55 gallon diesel tank.

Using current technology (ie, including retrofits to gas engines and dual fuel engines), it appears that -- compared to spark ignition gas engines -- CNG automobiles would produce about half the reactive VOC emissions, about the same NO_x levels, one-half to one-eighth the CO levels, and about 5 - 30% less CO_2. Some sources indicate that dual fuel vehicles will not improve on gas engines regarding ozone formation.

Dedicated CNG technology (i.e., engines designed specifically for CNG) would probably reduce reactive VOC emissions to 25% of less of those from gas engines, reduce NO_x by about 30%, and reduce CO to very low levels. It should be noted, though, that NO_x levels are strongly dependent on engine operating characteristics and catalyst type: some references indicate that considerably higher NO_x levels are very possible and that fully effective catalysts have not yet been developed. Unburned methane will also contribute to the greenhouse effect.

Using CNG in diesel engines should reduce particulates. Carbon monoxide emissions will probably not be reduced but are already low. NO_x emissions, however, may increase or decrease depending on engine type and load. VOC emissions should be much lower than those from conventional diesels.

CNG engines also produce higher formaldehyde emissions than gas vehicles. Catalysts will probably be required to deal with these emissions (which may be carcinogenic) as well as to reduce

unburned methane. Data on catalyst efficiency and durability are lacking at present.

Different sources indicate substantially different emission rates. Some manufacturers of prototype retrofit kits claim very low levels of CO and reactive hydrocarbons, but to date these are not available on a commercial basis.

Methanol: Methanol can be used either neat (100% methanol) or as M85 (85% methanol and 15% gasoline to improve cold starting performance).

Methanol use may lower emissions. Current technology engines (including dual fuel engines) using M85 fuel produce about the same reactive VOC as gas engines, 10% less NO_x, and about the same CO. In other words, there is only a small improvement in ozone-causing emissions. Dedicated engines running on neat methanol may produce only 25% as much VOC (some sources indicate zero hydrocarbons) and 10% as much CO; NO_x will be about the same as gas engines. Evaporative emissions will also be low.

Various sources differ considerably in their emission estimates. The figures above are from a report dated 1990. Another report dated 1988 indicates substantial variation of in-use vehicle emissions depending upon the size of engine (four cylinder cars produced about twice the CO and NO_x of eight cylinder vehicles) and the particular fleet tested (one fleet produced about almost twice the emissions of the other). Overall these tests indicated that M85 eight cylinder vehicles produce less hydrocarbons than gas autos, about the same NO_x, and 1-3 times the CO.

Methanol has several disadvantages. It is toxic: about 20 times as toxic as gasoline. Ingestion of one ounce of methanol will cause blindness; two ounces is fatal. Absorption through the skin of large amounts can cause equally serious problems, although small spills will only cause burning and rashes. Methanol fires of spilled fuel are very difficult or impossible to see, causing a significant safety hazard during refuelling. Engines suffer from poor cold starting, poor lubrication (gas acts as a lubricant to the pistons, but methanol is poor at this), and produce four to eight times the aldehyde emissions of gas engines (aldehydes are photoreactive, cause eye irritation, and may be carcinogenic). These problems are probably solvable but the cost is not yet known. Reducing aldehydes and other pollutants will likely require catalysts; the durability of these is unknown. Fuel tanks for neat methanol would have to be twice the size of gas tanks and there is essentially no existing methanol infrastructure.

Emissions from the production of methanol from gas-based plants will be about equal to that of oil refineries, but production from coal-based plants will produce higher levels of pollutants.

In diesel engines, spark-assist will likely be necessary. Such engines will have energy consumption roughly equal to conventional engines, lower NO_x and low (or zero) particulates. Dual fuel vehicles will also share these characteristics. Proper ignition and lubrication may necessitate fuel additives: current additives would drive fuel operating costs to three times that of conventional engines.

Gasohols: Gasohols are made by blending gasoline with methanol (eg, M85) or ethanol. M85 was discussed above. Ethanol blends in older cars would produce about 4% less CO_2, 30% less CO, 15% higher NO_x, and 5% higher hydrocarbons, according to Environment Canada. Newer cars with 3-way catalysts burning gasohols would produce emissions indistinguishable from burning gasoline.

Liquid petroleum gas (LPG): The use of LPG requires only minor engine modifications. In Europe, vehicles are usually dual fuel and conversions are encouraged through tax incentives. Dual fuel vehicles have non-methane organic gas emissions of about half that produced by gas engines. Dedicated LPG engines would probably reduce ozone production from this pollutant to about 20% of that from gas engines. LPG dual fuel engines can produce high NO_x levels, however, almost twice that of gas engines; dedicated engines would likely reduce this to 60% of gas engine levels.

LPG can also be used in diesel engines, where it produces somewhat higher fuel consumption levels, but lower emissions and noise.

Overall, it appears that dual fuelled vehicles would be about the same as gas autos at ozone formation, but dedicated vehicles might be notably better.

LPG engines emit very low levels of CO.

Propane: Propane is similar to CNG as a fuel, but has the advantage of being more easily compressed and stored. Propane vehicles have disadvantages of high conversion costs (about $1,800 per vehicle), somewhat lower range (about 25% less than gas for fuel injected engines), and fire/explosion hazard if the fuel leaks. Because of safety considerations, it may be more suitable for fleet purposes, especially in rural areas.

Propane vehicles have overall lower operating costs since propane costs much less than gasoline. There is a good refuelling infrastructure in the GVRD but few refuelling stations in the City of Vancouver (i.e., refuelling stations in the GVRD are concentrated in the outlying areas, with few stations located in the City itself). Propane is a by-product of natural gas, and there is enough supply for roughly 4-5 times as many propane vehicles as now use it.

A recent test of a propane vehicle indicates in-use emissions of non-methane HC to be about the same as that from a gasoline engine, NO_x to be almost twice as high, CO to be roughly the same, and direct CO_2 production to be slightly lower. Because of the different composition of VOC gases, however, the ozone producing capability of the propane engine exhaust was estimated to be only about 60% that from gasoline engines even though the propane vehicle created more NO_x pollution.

Variable aromatic content gasoline: When the aromatic content of gas was varied from 10-30%, it was found that VOC decreased but olefins increased. Since each has about the same reactivity, total ozone production would not be affected.

Reformulated gasolines: These are "designer" gasolines that have been blended for specific applications (eg, one type might be for high ozone areas, another for high CO regions). Data from oil companies indicate possible changes to pollutants from newer vehicles in the area of +5% to -20% depending on pollutant and gas blend. Often, however, decreasing one pollutant increases another somewhat. Older vehicles may also benefit from such blends, but the direction of change may be opposite to that for newer vehicles.

Electricity: Electricity can be produced in vehicles from batteries or fuel cells. Both power sources have the advantage of producing almost no emissions of consequence.

Batteries, however, are very heavy (roughly half a ton), bulky, expensive (a van would cost about $60,000) and provide only about 60-100 miles of freeway range before they must be plugged in for "refuelling". Some designs can provide top speeds of only about 70 kph. The generation of electricity additionally may cause pollution, especially if from coal-fired plants, while hydro plants have their own set of associated environmental problems.

Fuel cells have potential but are severely constrained by the difficulties of storing the hydrogen they convert to electricity: hydrogen storage tanks of all types are very bulky and heavy, and there is currently no reason to think this can be improved significantly.

Conclusions

The most significant conclusion drawn from this review of the literature is that various sources often disagree as to the emissions resulting from these fuels. This is especially true in terms of the absolute amounts of pollutants formed, but the relative amounts compared to those from conventional engines are also often different. Based on the review, estimates can differ by as much as a factor of six. In addition, some studies consider tailpipe emissions only, while others include evaporative losses. Some sources quote emissions only in terms of grams per mile, while others estimate the amount of ozone that will be produced from NO_x and/or HC.

Such ozone estimates not only depend on the emission level of the pollutants, but also on the relationship assumed for production of ozone from the pollutant. In the case of HC, ozone production varies according to the exact composition of the many compounds that are included in this general classification (each of which has a different ozone production ability), and this in turn varies according to the type of fuel burned and the specific engine technology used. In the case of NO_x, ozone is not related to the levels of this gas in a simple manner, so estimating ozone levels is very difficult.

Overall it is clear that several measurement problems must still be overcome, particularly regarding tests of in-use vehicles rather than "test bed" engines, the changes that occur over the lifespan of the engines, and the variations caused by specific engine and emission control system characteristics.

There are a few studies that attempt to compare the liquid alternative fuels to gasoline with regard to pollutants on the basis of actual in-use vehicle emissions or computer models that use in-use emissions data and fleet composition data to estimate total fleet emissions. In general, these studies indicate that CNG, propane, and LPG all have the potential to reduce ozone levels, while simultaneously reducing direct CO_2 emissions by a small amount compared to using gasoline. In most studies, this is accomplished through reduction -- sometimes great reduction -- of the VOC levels. NO_x levels from the liquid alternative fuels, on the other hand, often are only somewhat lower -- or even considerably higher -- than those emitted by conventional gasoline engines.

M85 does not appear to be as good a candidate for reducing the greenhouse effect. Studies that show it to be better than gasoline in terms of reactive emissions indicate it is only slightly better, and several studies show it to be worse.

In summary, the evidence on alternative fuels, as they relate to NO_x/VOC emissions, is not conclusive. Although many of the studies showed a decrease in VOC emissions, NO_x emissions could be higher or lower than gasoline engines. Combined, it is not possible to definitively

conclude that alternative fuels will consistently provide benefits in the management of NO_x/VOC emissions.

Chapter 1

Introduction

What Is RDIS

RDIS is an acronym for Residual Discharge Information System. This micro-computer based system was designed to enable the compilation of emissions inventories, for diverse - pollutants. It was designed with easy to use menus, to simplify the tasks of entering and reporting emissions data on a yearly basis.

Emission information for both anthropogenic and non-anthropogenic sources are maintained within the system and enable the coverage of all the important sources of pollution in Canada. Since not all sources of pollution can be monitored, the system uses the concept **discharge factor** to automatically calculate the emissions from the sources for which emission data for specific pollutants are not available. With this discharge factor, which indicates the rate at which a contaminant is released to the environment as a result of some activity, the system as the capability to present a more complete picture of the emissions released at the provincial or national levels.

The RDIS is also equipped with some additional processing capabilities such as the speciation of Volatile Organic Compounds (VOC), and the griding of emissions which are required for activities such as emission modelling.

Hardware Requirements

The minimum hardware and software requirements your computer system needs to run RDIS are:

-> MS-DOS or PC-DOS compatible computer (AT or 386 compatibles).

-> MS-DOS or PC-DOS version 3.1 or later.

-> 1.2 megabyte 5.25" or 1.44 megabyte 3.5" floppy drive.

-> A hard disk with at least 20 megabytes of storage since the system requires a 3 to 5 megabytes of data per year depending on the province.

-> A wide carriage return printer with condensed mode capabilities.

-> The DOS config.sys file should have buffers=20 and files=40.

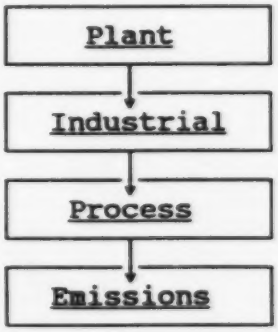
The hard disk requirements will also be greater if the VOC speciation and/or griding modules of the system are used. These modules create new files that can be used for further processing or reporting.

RDIS Overview

System Structure Description

The system is made up of a multitude of dBaseIV programs and of two types of data files that we qualify as related and primary. The related files are used as dictionaries within the system to define the various codes, while the primary files contain the actual inventory data. Although there are only 4 primary files, the gist of the system revolves around them. These primary files includes 4 main groups of information that we call **data blocks**.

-These blocks are named:



-The **Plant data block** includes basic location information for each plant such as thier address, city, lat/long. Other useful information like the plant contact person and its telephone number are also included.

-The **Industrial data block** includes information that characterises the industrial activities performed at the plant. It also includes temporal information required for modelling activities such as hourly and daily schedules of operations.

-The **Process data block** contains a description of the process along with some operational parameters required to perform emission estimates. Information on boiler types, fuel characteristics, process equipment, and the quantity of material produced are some of these useful parameters.

-The **Emissions data block** contains process specific emission data. Information such as the control device types, their efficiencies along with the quantity of pollutant released are all maintained in this data block. Details on the method used to obtain the emission values such as stack sampling tests, permit data, engineering estimate which are useful to analyze the accuracy of the emission quantities are also part of this block.

A key item is used in each of the above data blocks to retrieve information. The different key items used are:

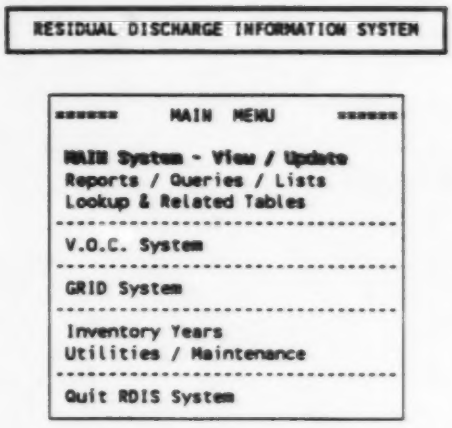
Data Block	Key Item
Plant block	plant code
Industrial block	Standard Industrial Code (SIC)
Process block	process code
Emission block	pollutant code

The interrelation between the data blocks is a one to many relationship. This translates into saying that each plant can have many industrial activities, and that each activity can have one or many processes, and each processes can have one or many pollutants emitted.

Six Steps To Obtain A Plant Information Summary

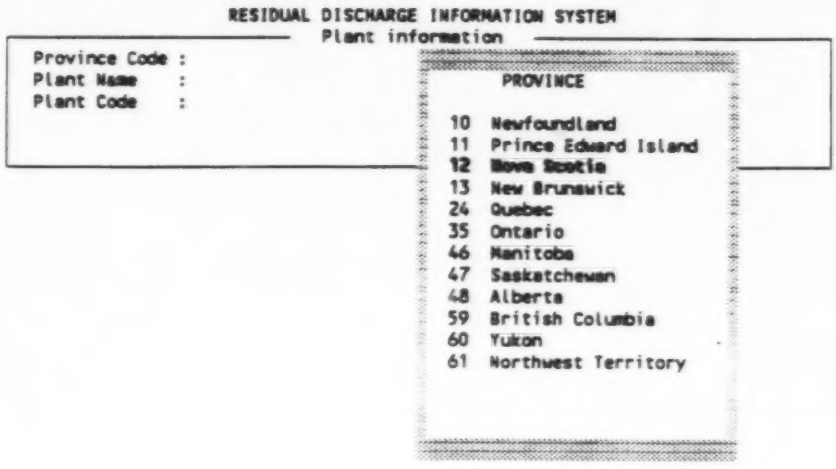
To gain an appreciation of what the system is about and experiment further with the above mentioned navigating keys, lets try a quick example that will enable you to obtain on one screen a summary of the information available for a given plant.

Step 1 **The Main Menu**



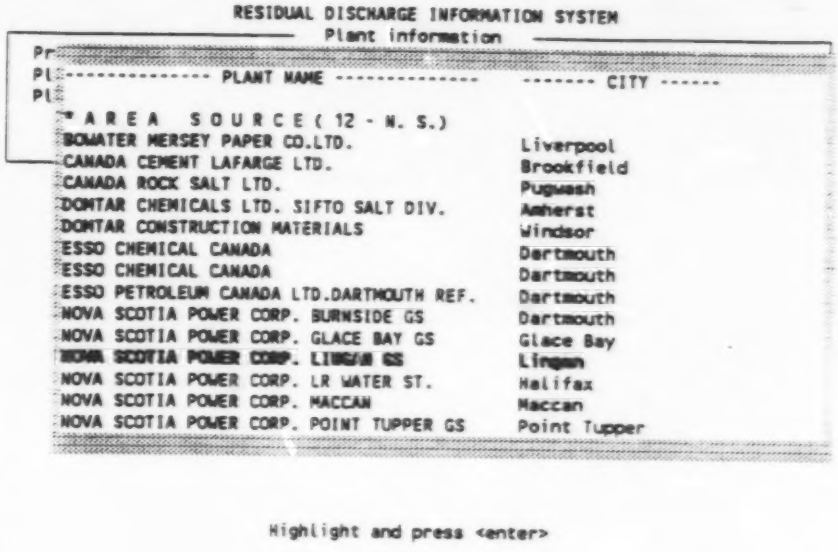
We are now ready to proceed with our example. Using the Up Arrow and Down Arrow keys select the first option on the main menu **MAIN System - View / Update**. A new screen then appears permitting the selection of a source.

Step 2 The Province Selection



The easiest way to select a source is to hit the **F1** key to obtain a list of the provinces available on your copy, and then with the Up Arrow and Down Arrow keys highlight the desired province and hit Enter (if only your province is available on your copy simply hit Enter). This simple selection procedure is the same for all selection windows of the system.

Step 3 **The Plant Selection**

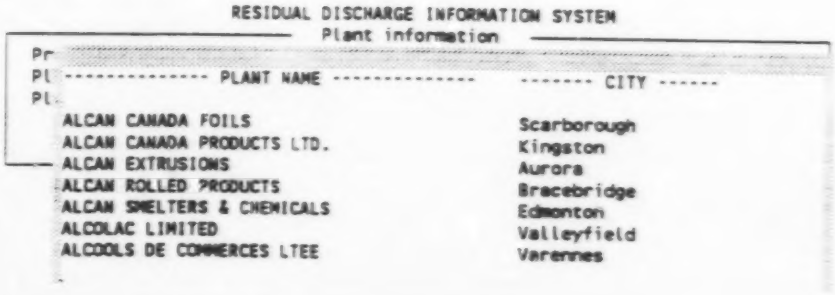

RESIDUAL DISCHARGE INFORMATION SYSTEM
Plant information
PLANT NAME
CITY
* A R E A S O U R C E (12 - N. S.)
BOWATER MERSEY PAPER CO.LTD. Liverpool
CANADA CEMENT LAFARGE LTD. Brookfield
CANADA ROCK SALT LTD. Pugwash
DOMTAR CHEMICALS LTD. SIFTO SALT DIV. Amherst
DOMTAR CONSTRUCTION MATERIALS Windsor
ESSO CHEMICAL CANADA Dartmouth
ESSO CHEMICAL CANADA Dartmouth
ESSO PETROLEUM CANADA LTD.DARTMOUTH REF. Dartmouth
NOVA SCOTIA POWER CORP. BURNSIDE GS Dartmouth
NOVA SCOTIA POWER CORP. GLACE BAY GS Glace Bay
NOVA SCOTIA POWER CORP. LINGAN GS Lingan
NOVA SCOTIA POWER CORP. LR WATER ST. Halifax
NOVA SCOTIA POWER CORP. MACCAN Maccan
NOVA SCOTIA POWER CORP. POINT TUPPER GS Point Tupper
Highlight and press <enter>

A list of the plants for the province selected will then be presented and again with the arrow keys the desired plant can be selected by hitting the ENTER key on the highlighted plant.

The above two steps can be simplified to one if:

a) the user knows the code of the desired plant (RDIS code or provincial code), it can be entered directly in the **Plant Code** area;

b) the beginning letter(s) of the name of the plant desired can be entered and a list of plants starting with those letters will be displayed (ex. entering ALC at the **Plant Name** area).



Step 4 **The Industrial Data Block**

RESIDUAL DISCHARGE INFORMATION SYSTEM

Plant information

Province Code : 12 (Nova Scotia)				Prov. Reference: None	
Plant Name : NOVA SCOTIA POWER CORP. LINGAN GS					
Plant Code : 120025			City : Lingan		
Total Emissions	PART:	990	SOx:	85240	THC: 62
(Tonnes)	CO :	3856	Nox:	10512	

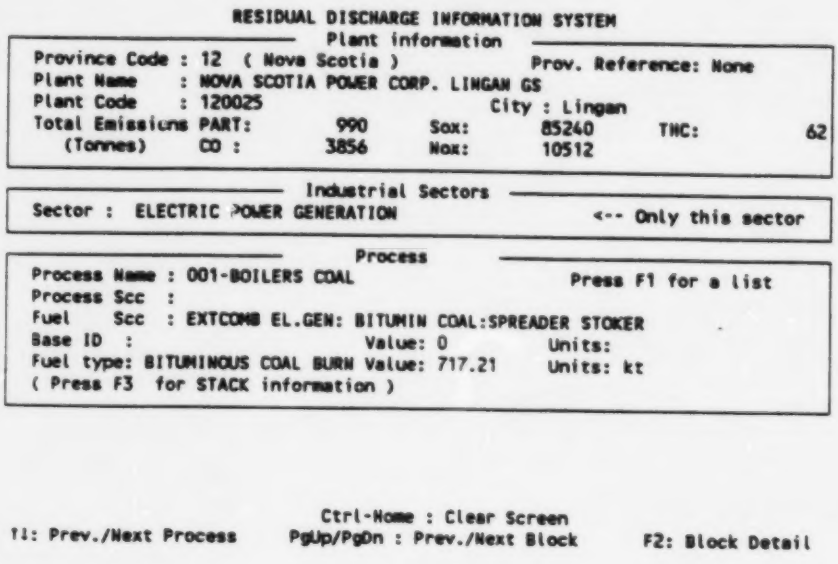
Industrial Sectors

Sector : ELECTRIC POWER GENERATION <-- Only this sector

Ctrl-Home : Clear Screen Ctrl-PgDn : Quick Update
f1: Prev./Next Sector PgUp/PgDn : Prev./Next Block F2 : Block Detail

Although a list of keys are listed at the bottom of the screen, we will limit ourselves to the use of the Page Down and the F1 key at the moment. Hitting the Page Down key at this point will display the first industrial sector of the plant. A list of the other industrial sectors can be obtained using the F1 key if other sectors exits. By highlighting the desired industrial sector and hitting the Enter key a selection can be made. In the case of our example above, the F1 key is not available since there is only one sector. The system also displays a message " <-- Only this sector " to indicate this situation.

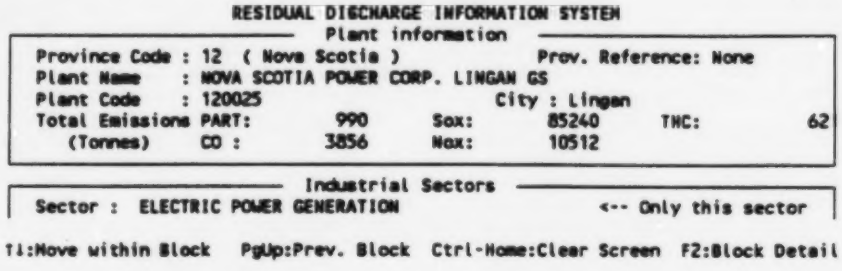
Step 5 The Process Data Block


RESIDUAL DISCHARGE INFORMATION SYSTEM
Plant information
Province Code : 12 (Nova Scotia) Prov. Reference: None
Plant Name : NOVA SCOTIA POWER CORP. LINGAN GS
Plant Code : 120025 City : Lingan
Total Emissions PART: 990 Sox: 85240 THC: 62
(Tonnes) CO : 3856 Nox: 10512
Industrial Sectors
Sector : ELECTRIC POWER GENERATION <-- Only this sector
Process
Process Name : 001-BOILERS COAL Press F1 for a list
Process Scc :
Fuel Scc : EXTCOMB EL.GEN: BITUMIN COAL:SPREADER STOKER
Base ID : Value: 0 Units:
Fuel type: BITUMINOUS COAL BURN Value: 717.21 Units: kt
(Press F3 for STACK information)
Ctrl-Home : Clear Screen
↑↓: Prev./Next Process PgUp/PgDn : Prev./Next Block F2: Block Detail

As it was mentioned earlier each plant can have a multitude of processes for each industrial activity. By hitting the Page Down key the first process for the selected industrial sector will be displayed. A list of the other processes can be obtained by using the F1 key.

Note: The stack parameters for the displayed process can also be viewed at this stage by hitting the F3 key (only available for process which are linked to a stack).

Step 6 The Emissions Data Block


RESIDUAL DISCHARGE INFORMATION SYSTEM
Plant information
Province Code : 12 (Nova Scotia) Prov. Reference: None
Plant Name : NOVA SCOTIA POWER CORP. LINGAN GS
Plant Code : 120025 City : Lingan
Total Emissions PART: 990 Sox: 85240 THC: 62
(Tonnes) CO : 3856 Nox: 10512
Industrial Sectors
Sector : ELECTRIC POWER GENERATION <-- Only this sector
↑↓:Move within Block PgUp:Prev. Block Ctrl-Home:Clear Screen F2:Block Detail

Hitting the Page Down key will make the emission data block appear on the screen. With this block displayed, one can have a global idea of the kind of information the system contains.

As you can see by the optional keys listed at the bottom of the screen, more detailed information can be viewed and edited with the use of the F2 key. If you want to try this example with another plant, you can hit the Ctrl-Home keys simultaneously to clear the screen and get to the plant data block for a new source selection.

Appendix B

Source Category / Industrial Sector Classification

Source Category / Industrial Sector	SIC Name	SIC
Industrial Processes		
Cement and Concrete Manufacture	Cement and Concrete Industry	35210
Forestry		
Pulp & Paper Industry	Kraft (Sulphate) Pulping	27110
	Neutral Sulphite Pulping	27109
	Newsprint	27120
	Other Paper Converters	27400
	Pulp and Paper Industry (Non-class)	27100
	Sulphite Pulping	27111
	Thermo-Mechanical Pulping	27108
Wood Industry	Forest Services Industry	05110
	Hardwood Plants	25210
	Logging Industry	04110
	Paperboard Industry	27130
	Particle Board Industry	25920
	Plywood & Veneer	25200
	Pulpboard Plants	25201
	Sawmills	25120
	Shingle and Shake Industry	25110
	Wood Preservation Industry	25910
	Wooden Box and Pallet Industry	25610
	Wooden Door and Window Industry	25430
	Misc. Wood Industries	25900
Mining		
Asbestos Production	Asbestos Production	06210
Coal Industry	Coal Industry	06300
Mining and Rock Quarrying	Limestone Quarries	08120
	Mining and Rock Quarrying	09290
	Molybdenum Mines	06150
Oil & Gas Production		
Crude Oil Production	Conventional Crude Oil and Nat Gas	07113
Natural Gas Processing	Natural Gas Processing Industry	07110
Tar Sands	Non-conventional Crude Ind.	07120
Other Industrial Fuel Combustion	Industrial Fuel Combustion	56223
Other Industries		
Asphalt Production	Asphalt Production	06210
Bakeries	Bakeries	10720
Clay Products	Clay Product Industry	35111
Grain Industries	Grain Handling & Milling	47110-47113
Paint & Varnish Manufacturing	Paint & Varnish Manufact.	37510
Other Chemicals	Ammonia Production	37130
	Ammonium Nitrate Production	37143

	Ammonium Phosphate	37115
	Ammonium Sulphate	37113
	Chemical Fertilizer & Fertilizer Mtls	37219
	Elemental Phosphorus Production	37112
	Fertilizer Prod Ammonium Nitrate	37210
	Lime Manufacture	35810
	Magnesium Production	29594
	Nitrate Fertilizer - Urea	37220
	Other Manufactured Products Ind.	39990
	Phosphate Acid Prod. Thermal	37118
	Red Phophorus Production	37141
	Salt Production	06250
	Sinlge Superphosphate	37116
	Sodium Carbonate (Soda Ash)	37110
	Sodium Chlorate Production	37142
	Sodium Nitrate Production	37144
	TNT Production	37145
	Triple Superphosphate	37117
Other Industries	Agricultural Implement Industry	31100
	Aircraft & Parts Manufacture	32100
	Asphalt Roofing Manufacturers	27200
	Battery Maufacture	33700
	Brewery Products Industry	11310
	Carpet Mat & Rug Industry	21600
	Coffin & Casket Industry	25810
	Coke Ovens not in Steel Plants	36990
	Confectionery Manufacturing	13100
	Dairy Factories	10500
	Distillery Products Industry	11210
	Electric Wire & Cable	33800
	Engrav. Stereotyping Industry	28700
	Fabric Structure Metal Industry	30200
	Feed Industry	10530
	Feed Manufactures	12300
	Fibre Preparing Mills	21100
	Fish Products Industry	10210
	Flour Mills	12400
	Fluorspar Processing	06291
	Frozen Fruit & Vegetable Industry	10320
	Fruits & Vegs. Canners/Preservers	11200
	Glass Manufacture	35620
	Gold Roasting	06110
	Gypsum Processing	35930
	Heating Equipment Manufacturers	30700
	Industrial Inorganic Chemical Ind.	03711
	Leaf Tobacco Processing	12110
	Leather Tanneries	17200
	Lubricating Oil & Grease Industry	36120
	Major Appliances	33200
	Meat & Meat Products Industry	10110

Metal Rolling Casting, Extruding	29800
Metal Stamp. Press & Coating	30400
Mineral Wool	35400
Misc. Electrical Products	33900
Misc. Machinery Equipment	31500
Misc. Manufacturing Industries	39900
Misc. Metal Fabric. Industry	30900
Misc. Food Industries	13900
Motor Vehicle Manufacture	32300
Mushroom Production	19000
Nepheline Syenite Processing	06292
Non-Metallic Mineral Insulating Mat.	35940
Office, Store Machinery	31800
Other Chemical Products Industries	37990
Other Fabricated Structural Metal Prod	30290
Other Millwork Industries	25490
Other Non-Metal Mineral	35900
Other Transport Services	51700
Other Waste Materials, Wholesale	59190
Paper Box & Bag Manufacturers	27300
Pharmceuticals, Medicines	37400
Phosphate Processing	06290
Plastic Products	16110
Potash Processing	06240
Power Boiler & Heat Exchanger Ind.	30110
Printing & Publishing	28900
Pyrrhotite Roasting	06172
Railroad Roll. Stock Industry	32600
Refactories Industry	35910
Rubber Products Industries	15990
Sand & Gravel Processing (Pits)	08210
Shipbuilding and Repair Industry	32710
Silica Processing	08211
Slaughter & Meat Processing	10100
Soft Drink Industry	11110
Steel Pipe and Tube Industry	29210
Stone Processing	08110
Stone Processing (Building Stone)	35990
Sugar Refineries	13300
Textile Dyeing & Refining	21800
Tire & Tube Manufacturing	16300
Uncoded or Undefined Industrial Act.	99990
Urban Transit Systems	50900
Vegetable Oil Mills	13500
Wineries	14700
Wooden Kitchen Cabinet & Bath.	25420
Wool Yarn Mills	19300

Petrochemical	
Carbon Black	
Carbon Black Industry	
Carbon Black	37111
Other Petroleum & Coal Products	36900

Petrochemical Industry	Acethaldehyde Production	37139
	Industrial Chemicals (General)	37800
	Ketene Acid Production	37136
	Mixed Fertilizers	37200
	Nitric Acid Production	37114
	Paint and Varnish	37500
	Petrochem	37800-37859
	Petrochemical Industry-Isobutylene	37131
	Plastic & Synthetic Resins Fabrication	37312
	Soap & Cleaning Compounds	37600
	Sulphuric Acid Production	37119
	Synthetic Textile Mills	20100
Plastics & Synthetic Resins Fab.	Plastics & Synthetic Resins Fab. Area	37313
Petroleum Refining	Petroleum Refining	36100
Primary Metals		
Aluminum Production	Aluminum Production	29510
	Carbon & Graphite Electrodes	33990
Copper and Nickel Production	Cu Smelting & Refining	29590
	Ni Smelting & Refining	29592
Ferrous Foundries	Ferro-Alloys Manufacturing	29110
Iron Ore Mining	Iron Ore Mining and Beneficiation	06170
Lead and Zinc Production	Pb Smelting & Refining	29990
	Zn Smelting & Refining	29992
Fuel Combustion		
Commercial Fuel Combustion	Commercial Fuel Combustion	56222
	Commercial Printing	28600
	Correctional Services	81220
	Defence Services	90200
	Department Stores	64200
	Education Related Services	80900
	Elementary & Secondary Schools	80100
	Gas Distribution	54700
	General Administrative Services	83590
	General Hospitals	86110
	Greenhouse Products	01630
	Hotels and Motor Hotels	91110
	Hotels, Restaurant, Taverns	87500
	Insurance, Real Estate Agencies	73500
	Local Administration	95100
	Other Bus. Manag. Services	86900
	Other Governemnt Services	99100
	Other Health Services	82700
	Other Miscellaneous Services	89900
	Other Recreational Services	85900
	Other Repair Services	99490
	Paint and Body Repair Shops	63520
	Religious Organizations	83100
	Research Administration	82760

		Savings Credit Institutions	70200
		Sports & Recreation Clubs & Services	96530
		Sports & Recreation Clubs	96590
		Universities & Colleges	80500
	Electric Power Generation	Electric Power Generation	49110
	Residential Fuel Combustion	Apartment Gas-Oil-Coal	99210
		Religious Organizations	98110
		Residential Fuel Combustion	56221
	Residential Fuelwood Combustion	Residential Fuelwood Combustion	56224
Transportation			
	Aircraft	Aircraft	45110
	Automobiles	Gasoline Powered Automobiles	45890
	Heavy-Duty Diesel Vehicles	Heavy-Duty Diesel Vehicles	45604
	Heavy-Duty Gasoline Trucks	Heavy-Duty Gasoline Trucks	45601
	Light-Duty Gasoline Trucks	Light-Duty Gasoline Trucks	45600
	Light-Duty Diesel Trucks	Light-Duty Diesel Trucks	45603
	Marine	Marine	45400
	Motor Cycles	Gasoline Powered Moter Cycles	45891
	Off-Road Use of Gasoline	Off-Road Use of Gasoline	45894
		Snowmobiles	45892
	Other Diesel Vehicles	Other Diesel Vehicles	45602
	Railroads	Railroads	45310
	Tire Wear	Tire & Tube Industry (Tire Wear)	15111
Incineration			
	Other Incineration	Commercial Incin. (Solid Waste)	49993
		Industrial Incineration (Solid Waste)	49992
		Municipal Incineration	49990
		Other Utilities (Incineration)	57900
		Sewage Sludge Incineration	49991
	Wood Waste Incineration	Wigwam Burners	04111
Miscellaneous			
	Application of Surface Coatings	Painting & Decorating	42751
	Cigarette Smoking	Other Tobacco Prod. (Smoking)	12220
	Dry Cleaning	Dry Cleaning Plants	97211
	Fuel Marketing	Diesel Oil Marketing	51112
		Gasoline Fuel Marketing	51111
	General Solvent Use	General Solvent Use	65321
	Pesticides and Fertilizer Application	Other Services Incl. Agricultral Crops	02290
		Pesticides (Crop Dusting & Spraying)	02220
	Slash Burning	Slash Burning	04120
	Structural Fires	Firefighting Services	82240
	Transmission Lines	NA	NA
	Anesthetics/Aerosols	NA	NA
	Water Treatment	NA	NA
Open Sources			
	Agricultural Operations	Agricultural Wind Erosion & Tilling	02390

Animal Waste	Animal Waste	02190
Construction	Bridge, Road Construction	41210
	Excavating & Grading	42141
	Heavy Construction	41190
	Non-Residential Construction	41200
	Residential Construction	40110
	Water, Sewer, Construction	41220
Dust From Paved Roads	Dust From Paved Roads	45911
Dust From Unpaved Roads	Dust From Unpaved Roads	45893
	Truck Transportation on Gravel Roads	45610
Forest Fires *	Other Forestry Services (Forest Fires)	05120
Mine Tailings	Mine Tailings	09291
Human Waste	NA	NA

* Forest fires are considered as biogenic sources for the purposes of this study and therefore not included as open (anthropogenic) sources.

APPENDIX C

SUMMARY OF THE METHODOLOGIES USED TO CALCULATE N_2O EMISSIONS

CALCULATION OF N_2O POINT AND AREA SOURCE EMISSIONS USING THE RESIDUAL DISCHARGE INFORMATION SYSTEM (RDIS)

Note: In the following, commands typed within { } refer to options the user may select from RDIS menus.

Since RDIS presently does not include N_2O, we had to incorporate this pollutant into the system, proceeding as follows:

First, all plants included in RDIS and situated in the Lower Mainland were deleted from the databases system. This was necessary in order to avoid data redundancies when data from LOMEI (Lower Mainland Emission Inventory) were to be incorporated into the resulting files.

In order to summarize the data RDIS provided, several new files were created from the various data files in RDIS to pull the needed information together and to better identify processes, base quantities, units, and the like.

Not needing to reach the plant-specific level to estimate the emissions of N_2O, we calculated emissions on the SCC level. RDIS differentiates between fuel SCCs and base SCCs. Therefore, a selection of SCCs had to be made from these files. We selected all SCCs occurring in British Columbia with NO_x emissions >0, although there are some variations to this.

Using the selected SCCs and having corrected fuel quantities and discharge units for a number of processes, we created an N_2O emission factor file which was later appended to the RDIS emission factor file. RDIS provides more than 10 different emission calculation/estimation methods. In our case, the actual emission calculations were carried out using the option {Utilities/Maintenance} {Calculate Emissions with NAPAP} {For a Contaminant} within RDIS. This option makes use of a file which contains US EPA NAPAP emission factors, and it is to this file to which our emission factors were appended. SCCs and emission factors may be added, deleted or changed here, but only <u>one</u> emission factor may be assigned to each listed fuel or base SCC.

Because RDIS only accepts compatible units, our emission factors had to be converted to the units RDIS used for each SCC. Some units could not be converted (for example: RDIS factor for wood= kg pollutant per coating line; our factor for wood = kg pollutant per t of wood).

For the time being, the only available N_2O emission factors for point sources are factors for the stationary combustion of coal, oil, gas or wood. These can be applied directly to calculate the emissions once the type of fuel and the fuel units of a process have been identified. However, where production quantities (such as emissions per tons of ore mined, coal dried, gas, P_2O_5 or air dried pulp produced) rather than fuel quantities were given, a direct application of our emission factors was not possible. In these cases, N_2O emissions were calculated for the fuel combustion part of a process alone or an emission factor was derived by assuming that N_2O (production

based)/N_2O (fuel based) emission ratios are equivalent to NOx (production based)/NO_x (fuel based) ratios. (The equation can be solved for a N_2O (production based) emission factor):

N_2O emissions from fuels:
For a given fuel SCC, the base quantity and the base quantity name were identified using lookup files provided in RDIS. N_2O emissions were then calculated using the emission factor for the corresponding fuel. No emission factors were assigned to SCCs with unidentified fuels or with incorrect units where these could not be determined. For solid waste incineration the factor for burning wood was used.

N_2O emissions from processes:
For emission sources which had been assigned both a base and a fuel SCC, N_2O emissions were calculated for the fuel combustion part of the process only. In most cases, a base SCC was associated with a fuel SCC with one given fuel. Some fuel SCCs, however, apparently serve as summary categories and include several different fuels. Since only one factor per SCC can be input to the RDIS emission factor file, we had to determine the fuel which was most commonly used and apply the appropriate emission factor.

Several base SCCs were not associated with fuel SCCs. The following two examples illustrate in detail how an emission factor for these categories was calculated:

EXAMPLE 1:

SCC = 31000293: Natural Gas Production.
Processname: natural gas fired compressors

1) NO_x emission factor for natural gas fired compressors (taken from RDIS):
--> 54464 kg NOx/MM m3 of gas

2) N_2O emission factor for burning of natural gas:
--> 13.884 kg N2O/MM m3 of gas

The N_2O factor for burning natural gas is 0.0255 % of the NO_x emission factor.

3) NO_x emission factor for natural gas fired compressors in gas production (taken from RDIS):
--> 4804.69 kg /MM m3 of gas produced

4) The derived N_2O emission factor for natural gas production is:
--> 0.0255 % * 4804.69 kg NO_x/MM m3 of gas produced.
--> 1.2248 kg N_2O/MM m3 of gas produced.

EXAMPLE 2:

SCC = 30700194: Pulp production
Processname: Recovery boilers for air dried pulp production

For a total of 23 listed processes only 5 were associated with a fuel SCC (10201201: burning of solid waste). In order to calculate the emissions for all processes within this SCC, an emission factor for the base SCC was calculated using the method shown below and assuming that all sources burn oil. The fuel SCCs for these sources had to be deleted from the files for reasons already mentioned above.

1) NO_x emission factor for recovery boilers fired with grade 6 oil (taken from RDIS):
--> 6.59 kg NO_x / m3 of oil

2) N_2O emission factor for burning of oil:
--> 0.08277 kg N_2O / m3 oil

The N_2O factor for firing recovery boilers is 1.25 % of the NO_x emission factor.

3) NOx emissions factor for recovery boilers for air dried pulp production (taken from RDIS):
--> 0.95 kg/t of air dried pulp produced

4) The derived N_2O emission factor for natural gas production is:
--> 1.25 % * 0.95 kg NOx/t air dried pulp produced
--> 0.01193 kg N2O/t air dried pulp produced.

Gridding N_2O Emissions with RDIS

The emissions were put on the 127 * 127 km2 grid by selecting the menu points {Grid system} {Generate emissions by grid} {Common pollutants} and choosing "nitrous oxide" from {Pollutant list}.

First, however, the grid file had to be prepared by selecting {Grid system} {Prepare the "127 km2" grid file}, a utility which prepares the prorating factors which serve to distribute the emissions over the province. The resulting file lists emissions per SIC and grid square.

Since grid square # 67 (row=45, col=42) lies completely outside of BC, and the emissions allocated to it stem from a BC community, its emissions were added to the adjacent grid square # 55 (row=44, col=42).

Then the N_2O emissions were totalled for each of the 80 grid squares to a summary grid file which also contains all anthropogenic and biogenic emission sources for NO_x, VOC, and N_2O. Finally, after all emissions had been compiled, reviewed and edited, all anthropogenic and all biogenic N_2O, VOC and N_2O emissions were converted to CO_2 equivalents and added for each grid square.

Incorporating Data from the LOMEI (Lower Mainland Emission Inventory) into the Gridded System

Using a converted data file from the GVRD, we estimated N_2O point source emissions as a percentage of NO_x emissions. The file included a list of permitted point sources, their NO_x emissions, the type of fuel burned, SCCs, and in a few cases the actual fuel quantity burned. The total NO_x emissions in the file account for 97.3 % of the Lower Mainland point source NO_x emissions (as reported in one of the Lower Mainland Emissions Inventory Report volumes).

The methodology applied:

For every SCC in the GVRD point source emissions file we looked for an uncontrolled NO_x emission factor in RDIS. We then calculated the ratio:

N_2O emission factor for the combustion of the fuel used/NO_x emissions factor for the given SCC, and multiplied this fraction by the NO_x emissions in the GVRD point sources file.

We used this number as a crude approximation of the N_2O emissions.

In many cases, however, a specific SCC in the GVRD point source emissions file was not included in RDIS. Thus, we often didn't have a NOx emission factor for a given SCC. In these cases, we averaged the N_2O/NO_x ratios obtained above for all plants burning the same fuel. Where the fuel type was unidentified, an average ratio for both oil and gas fuels was assigned to the appropriate SCC.

Averaging N_2O/NO_x ratios for plants burning the same type of fuel:

Fuel burned	
Natural gas	---> 0.00745 (4)
Hog fuel, wood waste	---> 0.16416 (5)
Oil	---> 0.01647 (3)

Others (unidentified) ---> average of gas/oil averages: 0.012

(In parentheses: number of SCCs averaged)
The averaging of factors, however crude, does reflect that gas is the cleanest fuel, followed by oil, and that wood has the greatest N_2O emissions.

Eliminating Data Redundancies Between RDIS and LOMEI

Redundant data (refer to sections 3.0 and 3.4 of the report for a detailed analysis) were deleted directly in RDIS files and in the final grid summary file, and, where appropriate, were redistributed to the rest of the province using the most appropriate prorating factors.

CALCULATION OF N_2O EMISSIONS FROM SOURCES NOT (OR ONLY PARTIALLY) INCLUDED IN RDIS

Power Line Coronas

A) N_2O Emission Estimates from Power Lines

N_2O emissions from high voltage transmissions lines were estimated for circuits greater than 138 kV according to the method outlined in Hill et al (1984). They are a function of line voltage, line loss and line length. The data for B.C. were provided by B.C. Hydro.

Length of Transmission Lines in British Columbia

Length of 500 kV transmission lines	: 5344 km (3313.28 miles)
Length of 360, 287 and 230 kV transmission lines	: 3927 km (2434.74 miles) (mostly 230 kV lines)

Source: B.C. Hydro (Doug Cave: 293-5802, K.C. Lee: 663-4227).)

The average corona loss and N_2O emissions from high voltage power lines in the United States for the year 1980 were estimated in Hill (et al, 1984) as follows:

Mean line voltage (kV)	circuit miles	average corona loss in kW/mile	average corona loss in J/year
362	35451	3	3.354E15
550	17687	6	3.347E15
800	3077	13	1.260E15

From this it may be inferred that:

Corona loss (J/yr) = circuit miles * average corona loss (kW/mile) * 3.15333E10

Corona Losses Estimated by B.C. Hydro
(typical yearly values for foul and fair weather)

for the 500 kV lines:	3.48 kW / km = 5.6 kW / mile
for the 360, 287 and 230 kV lines:	2 kW / km = 3.2 kW / mile

Source: B.C. Hydro (K.C. Lee: 663-4227).

Thus, the estimated corona loss for British Columbia is:

[(3'313.3 * 5.6) + (2'434.7 * 3.2)] * 3.15333E10 = 8.3E14 J/yr

In Hill (et al, 1984) an N_2O production efficiency of approximately 4E16 molecules per joule is assumed for high voltage power lines.

Thus, for British Columbia, an estimated 8.3E14 * 4E16 = 3.3E31 molecules N_2O are produced on average per year.

From Hill (et al, 1984) it further follows that 3.2E32 molecules of N2O are equivalent to 23'000 t of N_2O. Therefore, 3.3E31 molecules amount to 2'388.4 t N_2O.

Using the above data, we conclude that roughly 2'400 t N_2O are generated per year from high voltage power lines in British Columbia. Using a B.C. Hydro Survey Map (1990), the transmission line corridors and their locations within the grid were identified and the N_2O emissions allocated accordingly.

B) Ozone and NO_x Emission Estimates from Power Lines

In Roche et al (1973), experimentally determined ozone and NO_x production rates for single and bundle transmission line conductors in dry and wet corona are given as follows:

Ozone: from $0.31E^{-2}$ lb/kWh corona loss to $0.81E^{-2}$ lb/kWh corona loss ($1.406E^{-3}$ to $3.67E^{-3}$ kg/kWh corona loss)

NO_x: from $0.073E^{-2}$ lb/kWh corona loss to $0.09E^{-2}$ lb/kWh corona loss ($3.31E^{-4}$ to $4.08E^{-4}$ kg/kWh corona loss)

Applying the methodology outlined above for N_2O to these numbers, the yearly production rates of ozone and NO_x from transmission lines in British Columbia are estimated at :

325 tonnes to 850 tonnes of ozone per year, and 75 tonnes to 95 tonnes of NO_x per year.

N_2O Emissions from the Application of Nitrogen Fertilizers

A certain percentage of nutrient-N in fertilizers containing nitrogen is emitted as atmospheric N_2O upon application. We estimated this loss of nitrogen as N2O from N-fertilizers at 1.2 % of the nutrient N applied (Environment Canada, 1991b; Anderson et al, 1987; Eichner, 1990; Conrad et al, 1983).

Because it was not clear what kind of fertilizers were included in RDIS, we calculated N_2O emissions from N-fertilizers using another source. The Western Canada Fertilizer Association in Surrey provided the following statistics:

- Nitrogen (N) fertilizers sales in B.C. by region (Central and South B.C. and the Peace River

Block),
- Nitrogen N fertilizers used in BC by region

The amount of plant nutrients (in this case nitrogen) may be obtained by multiplying retail fertilizer sales for different nitrogen containing fertilizers by their N-content.

Nitrogen Content of Different Fertilizers

Anhydrous ammonia	: 82 %
Urea	: 46 %
Ammonium nitrate	: 34 %
Ammonium sulphate	: 20 or 21 %
M.AmP.	: 11 %
D.A.P.	: 18 %
A.P.S.	: 16 %
Nitrogen solution	: 28 %

Source: Western Canada Fertilizer Association; Retail Fertilizer Sales Survey.

The results are shown in the following table:

NITROGEN (N) FERTILIZERS - EXPRESSED AS TONNES OF NUTRIENT N - USED IN BC BY REGION AND ESTIMATED EMISSIONS OF N_2O (IN PARENTHESES). YEAR ENDING JUNE 30, 1985 - 1990:

	Central + South B.C.	Peace River Block B.C.	Total B.C.
1985	15'734 (188.8)	11'691 (140.3)	27'425 (329.1)
1986	15'520 (186.2)	18'017 (216.2)	33'537 (402.4)
1987	14'707 (176.5)	12'265 (147.2)	26'972 (323.7)
1988	14'315 (171.8)	16'227 (194.7)	30'542 (366.5)
1989	16'816 (201.8)	23'350 (280.2)	40'166 (482.0)
1990	15'841 (190.1)	13'828 (165.9)	29'669 (356.0)

Because of limited available data, these fertilizer-based N_2O emission estimates do not include potential emissions resulting from the application of manure. In some parts of B.C., such as the Fraser Valley, where the field application of manure is appreciable, N_2O emissions may be significant.

Biogenic N_2O Emissions from Soils (Excluding Emissions from the Application of Fertilizers)

Our gridded files use the grid structure provided by Environment Canada. In order to be able to

overlay this grid on a soil map (Farley, 1979), we photocopied and enlarged a map showing the same grid system that is used for RDIS. From this enlargement, a clear film (overlay) was produced. Then, after numbering the grid squares on the overlay, the percentage of land or water outside the BC land mass (Pacific Ocean, Alaska, Yukon, Northwest Territories, Alberta or the United States) was estimated for each of them.

The emission factors (for N_2O and NO_x•) used are:

Soil order	N_2O flux (kg N_2O-N/km²/y)	NO_x flux (kg NO_x-N/km²/y)
Chernozemic	107.4	2.6
Solonetzic	44.9	12.2
Luvisolic	27.2	5.8
Podsolic	225.4	272.8
Brunisolic	47.0	20.0
Regosolic	6.7	0.4
Gleyosolic	26.3	0.7
Organic	157.9	156.4
Rockland	5.0	0.3

• The described methodology also applies to NO_x.

Using the soil map, and for each of the 80 grid squares, we then estimated the percentage that different soil orders cover of the BC land mass.

All information was stored in a file. Dominantly lithic soils were categorized under the heading "rockland". The emission factors were applied to all soil orders with the exception of cryosolic soils, for which there were no emission factors available.

Error sources:

Judgement error from visual estimation of the percentage of BC's land mass or the area covered by different soil orders within each grid square. As an aid, we subdivided a grid square into 16 parts and used it as a second overlay.

The enlargement of the map showing the grid system shows a distortion error when overlaid on the soil map.

A comparison of the results presented here with the estimates made by Environment Canada (1981b) follows:

a) Comparison of estimated total land area within B.C.:

	Area in km^2	Difference
Actual area (Farley, 1979)	948000 km^2	-
Area estimated here (*)	972300 km^2	+ 2.6 %
Area estimated (Environment Canada, 1981b)	886194 km^2	- 6.5 %

(*) Area includes all freshwater bodies within B.C.

Since freshwater bodies cover about 2 % of the province (Farley, 1979), the additional estimation error of our total is not greater than 5 %.

b) Comparison of N_2O emissions for B.C. from different soil orders:
(Emissions are in t N_2O-N. To convert to t N multiply by 14/44).

Soil Order	Greenhouse Gases Inv.	Env. Canada (1981b)
Luvisols	6140	6500
Regosols	13.5	13
Podsols	91170	40266
Organic	2185	6186
Brunisols	8754	5950
Rockland	198	1175
Gleyosolic	515	142
Chernosem	1408	2272
Solonetzic	113	43
Total	~ 110500	~ 62500

The total emissions differ by a factor of about 1.75. Since both our study and Environment Canada (1981b) use the same emission factors, the differences are solely due to the area estimations made for different soil orders. The largest absolute difference being the estimated area of podsols - Greenhouse Gases Inventory = 40 % versus 20 % in Environment Canada (1981b) - we asked the B.C. Ministry of Agriculture and Fisheries to confirm or reject our area estimation. We did receive a confirmation of our number for podsols (B.C. Ministry of Agriculture and Fisheries, 1991), however, the reference given used the same source we had used.

N_2O Emissions from Mobile Sources

We worked with the following emission factors from Environment Canada (1991b):

Gasoline		
No catalyst	0.1873 kg/t	= 0.1408 kg/m3 (a)
New catalyst	0.3602 kg/t	= 0.2708 kg/m3
Aged catalyst	1.1931 kg/t	= 0.8971 kg/m3
Diesel	0.2923 kg/t	= 0.2542 kg/m3 (b)

(a) Density of gasoline: 750 kg/m3
(b) Density of diesel : 870 kg/m3

In RDIS, the base quantities given for different vehicle categories are:

- Number of movements for aircraft.
- Number of vehicles for automobiles (light duty gas vehicles), light-duty trucks (gas and diesel powered), motorcycles, heavy-duty trucks (gas and diesel powered).
- Amount of diesel oil burned for railway traffic and for other diesel vehicles in the agricultural, manufacturing, mining, construction, forestry, pipeline and public administration sectors.

To estimate the N_2O emissions of these three categories we proceeded as follows:

N_2O EMISSIONS FROM AIRCRAFT:

N_2O emissions from aircraft were estimated using average fuel consumption factors obtained from the US Environmental Protection Agency (EPA, 1985) for one representative aircraft type in each aircraft class. Given the similar properties of the two fuels, diesel fuel was used as a surrogate for aviation fuel, so that the N_2O emission factor for diesel combustion could be used.

Assumptions: Inflights are 1 hour duration; inflights = number of movements (=LTO) / 2.
Average LTO modes information from the US Environmental Protection Agency (EPA, 1985).

Aircraft class	Representative aircraft type
Jet aircraft	Boeing 737
Turboprop	De Havailland Twin Otter
Piston	Piper Navajo
Small piston	Cessna 150
Helicopters	none found

Aircraft class	Fuel burned/movement (kg)	Fuel burned/inflight (*) (kg)
Jet aircraft	495	1275
Turboprop	39	97.2
Piston	20.6	45.1
Small piston	3.6	11.6

(*) Approach mode for 1hr duration is assumed

N_2O emission calculations:

A) kg N_2O = kg/movement * movements / kg/m3 * kg/t)
(Number of movements from RDIS)

Jet : 495 * 21354 / 870 * 0.2923 = 3.55 t N_2O
Turbo : 39 * 25501 / 870 * 0.2923 = 0.33 t N_2O
Piston : 20.6 * 109578/ 870 * 0.2923 = 0.76 t N_2O
Small piston : 3.6 * 66740 / 870 * 0.2923 = 0.08 t N2O

B) (kg N_2O = kg/inflight * movements * kg/m^3)
Assumption: Inflights = number of movements/2

Jet : 1275 * 21354 / 2 / 870 * 0.2923 = 4.57 t N_2O
Turbo : 97.2 * 25501 / 2 / 870 * 0.2923 = 0.42 t N_2O
Piston : 45.1 * 109578/ 2 / 870 * 0.2923 = 0.83 t N_2O
Small piston : 11.6 * 66740 / 2 / 870 * 0.2923 = 0.13 t N_2O

Total aircraft emissions (A+B) = 10.67 t N_2O

N_2O EMISSIONS FROM VEHICLES

In a first step, we calculated the total fuel consumption per vehicle category in B.C. using the formula:

Fuel consumed = Number of active vehicles in the fleet * VMT * AFC / 100

where: VMT = Average vehicle kilometres travelled per year
AFC = Average fuel consumption per 100 km

The number of vehicles per category was taken from RDIS.

For each vehicle category using gasoline we then obtained the percentage of vehicles with:

- a new catalytic converter

- an aged catalytic converter
- no catalytic converter

and were thus able to apply the emission factors given above. The breakdown of catalytic converter use in 1985 was provided by Environment Canada.

The N_2O emission estimates per vehicle category are as follows:

(kg N_2O = percentage * fuel consumed in m^3 * emission factor in kg/m^3)

Autos (gas)
New catalyst: 0.069 * 2734185 * 0.2708 = 51 t N_2O
Aged catalyst: 0.598 * 2734185 * 0.8971 = 1467 t N_2O
No catalyst: 0.333 * 2734185 * 0.1408 = 128 t N_2O

Light duty trucks (gas)
New catalyst: 0.069 * 1251404 * 0.2708 = 23 t N_2O
Aged catalyst: 0.598 * 1251404 * 0.8971 = 671 t N_2O
No catalyst: 0.333 * 1251404 * 0.1408 = 59 t N_2O

Heavy duty trucks (gas)
No catalyst: 1.000 * 254949 * 0.1408 = 36 t N_2O

Motorcycles (gas)
No catalyst: 1.000 * 17581 * 0.1408 = 2.5 t N_2O

Light duty trucks (diesel)
No catalyst: 1.000 * 71494 * 0.2542 = 18 t N_2O

Heavy duty trucks (diesel)
No catalyst: 1.000 * 936541 * 0.2542 = 238 t N_2O

Total N_2O emissions from vehicles = 2693.5 t

N_2O emissions from marine vessels and off-road gasoline categories could not be estimated due to nonexistent or inappropriate base quantity data. For natural gas powered vehicles, neither base quantities nor total emission estimates are contained in RDIS.

N_2O EMISSIONS FROM RAILWAY TRAFFIC AND OTHER DIESEL VEHICLES

N_2O emissions for the third category were calculated by directly applying the N_2O emission factor for diesel given in the table above to the base fuel quantities provided in RDIS:

Total diesel consumed = 1239400 m^3
Total N_2O emissions = 1239400 * 0.2542 kg/m^3
= 315 t N_2O
Breakdown: 71 t N_2O from railway traffic, 244 t from other diesel vehicles

N_2O Emissions from the Production/Application of Anaesthetics and Aerosols

US production data acquired from the Ontario Ministry of the Environment (1991) was prorated based on population data to estimate N_2O emissions from these sources. The population of BC is approximately 1 % of the US population. The emissions are as follows:

Anaesthetics: 143 t N_2O
Aerosols: 7.5 t N_2O

APPENDIX D

NOx/VOC/O3 GREENHOUSE GAS EMISSION INVENTORY FOR B.C.
MAJOR SOURCE EMISSIONS (by SCC)

Note: For some SICs, only the emissions of major SCCs have been listed. The totals may therefore differ from those in Table 2.

SIC Name	SIC #	SCC Name	SCC #	Emissions (tonnes)
NOx Industrial Processes				
Cement & Concrete Manufacture	35210	Oil Fired Hot Water Boiler	10300501	0.4
		Rotary Kiln (dry process)	30500606	52
		Wet Scrubber Stack	10200501	0.2
Forestry				
Kraft (Sulphate) Pulping	27110	Wood Prod.\Sulfate Pulp\Recovery Boiler/Evap	30700194	4195
		Wood Prod.\Sulfate Pulp\Lime Kiln	30700196	4033
		Ext. Comb. Boiler Industrial Residual No.6 Oil	10200401	4205
		Ext. Comb. Boiler Ind\Nat. Gas 100+ GJ/hr\B.C.	10200691	414
		Ext. Comb. Boiler Ind\Nat. Gas 10-100 GJ/hr\B.C.	10200692	529
		Ext. Comb. Boiler Ind\Wood/Bark Boiler	10200992	1800
		Ext. Comb. Boiler Ind\Wood/Bark & Low Oil	10200998	136
Sawmills	25120	Ext. Comb. Boiler Ind\Nat. Gas\-10 GJ/hr/B.C.	10200693	116
		Ext. Comb. Boiler Industrial Wood/Bark Waste	10200901	281
		Ext. Comb. Boiler Industrial Wood/Bark Waste	10200904	174
		Ext. Comb. Boiler Industrial Wood/Bark Waste	10200905	5
		Ext. Comb. Boiler Industrial Wood/Bark Waste	10200906	137
		Solid Waste Displ Ind. Incineration Trench Burner	50300106	15
		Solid Waste Industrial\Incinerator\Conical Wood	50300195	2739
		Solid Waste Displ Industrial Open Burning Wood	50300201	2

SIC Name	SIC #	SCC Name	SCC #	Emissions (tonnes)
Mining				
Coal Industry	06300	Fluid Bed Dryer	30501091	1257
		Preparation Plant Heating Boiler	10500102	3
		Camp Refuse Incinerator	50300101	0.1
Oil & Gas Production				
Natural Gas Processing Industry	07110	Ext. Comb. Boiler Ind\Nat. Gas\10-100 GJ/hr/B.C.	10200692	744
		Ext. Comb. Boiler Ind\Nat. Gas\-10 GJ/hr/B.C.	10200693	8
		Int. Comb. Elec. Gen.\Nat. Gas\ Reciprocating\B.C.	20100292 + 20200292	7953
Other Industrial Fuel Combustion	56223	Stationary Source - Residual Oil	0013520	1400
Other Industries				
Industrial Inorganic Chemical Ind.	03711	Chemical Mfg Methanol General Production	30125001	2105
Brewery Products Industry	11310	Natural Gas Fired Boilers	10200691	458
Primary Metals				
Aluminum Production	29510	Al Elect Reduc\Coke Calcining	30300191	2022
		Al Casting\Gas Fired	30300193	20
Petroleum Refining	36100	Catalytic Cracking Fluid Cat. Cracker	30600201	881
		Natural Gas Heaters and Boilers	30600195	125
NOx LOMEI Industrial Point Sources				
Cement & Concrete Manufacture				
Non-Metallic Mineral	35210	GVRD (Non Metallic Mineral)	00055100	4293
Petroleum Refining	36100	Cat. Cracking Fluid Cat. Cracker &	30600201 &	
		Natural Gas Heaters and Boilers	30600195	20

SIC Name	SIC #	SCC Name	SCC #	Emissions (tonnes)
Other Industries	varied			852
Forestry				
Sawmills (Wood Industries)	25120	Wood Industry - Sawmill Production	00057100	613
Paper & Allied	27120	Wood products - Sawmill Operations Not Classified	30700897	605
Chemical Industry				
Industrial Inorganic Chemicals Ind.	03711	Chemical Mfg Miscellaneous Not Classified	30199999	268
NOx Fuel Combustion				
Commercial Fuel Combustion	56222	Stationary Source - Natural Gas Burned	00012100	2039
		Stationary Source - Liquid Petroleum Gas	00012200	104
		Stationary Source - Kerosene Burned	00012300	42
		Stationary Source - Distillate Oil	00012500	264
		Stationary Source - Residual Oil	00012520	263
Electric Power Generation	49110	Stationary Source Electric Power - Misc. Diesel	00014400	2012
		Ext. Comb. Boiler Elec. Gen. - Distillate Oil	10100501	38
		Int. Comb. Elec. Gen. Diesel	20100101	24
		Int. Comb. Elec. Gen. Diesel	20100102	1705
		Int. Comb. Elec. Gen. Natural Gas	20100291	132
	(Burrard Thermal)	Ext. Comb. Boiler Elec. Gen. Natural Gas	20100291	2200
Residential Fuel Combustion	56221	Stationary Source - Residential Natural Gas	00011100	2489
		Stationary Source - Residential Liquid Pet. Gas	00011200	105
		Stationary Source - Residential Kerosene	00011300	93
		Stationary Source - Residential Coal	00011400	12
		Stationary Source - Residential Distillate Oil	00011510	621
		Stationary Source - Residential Residual Oil	00011520	73

SIC Name	SIC #	SCC Name	SCC #	Emissions (tonnes)
NOx Miscellaneous				
Slash Burning	04120	Slash Burning	00033100	9033
NOx Incineration				
Wigwam Burners	04111	Solid Waste Incineration - Wood Waste Disposal	00032100	2100
Industrial Incineration	49992	Solid Waste Incineration - Multiple Chamber	00031300	65
		Solid Waste Incineration - Controlled Air	00031500	72
Municipal Incineration	49990	Solid Waste Gov't\Incineration\Not Classified (Burnaby Incinerator)	50100599	312
NOx Transportation				
Aircraft	45110	Off-Highway Mobile Source - Jet Aircraft	00023110	120
		Off-Highway Mobile Source - Turboprop	00023120	17
		Off-Highway Mobile Source - Piston Engine	00023130	1.4
		Off-Highway Mobile Source - Helicopters	00023140	3
		Off-Highway Mobile Source - Small Piston	00023150	0.7
		Off-Highway Mobile Source - Jet Aircraft Inflight	00023210	2836
		Off-Highway Mobile Source - Piston Inflight	00023240	92
		Off-Highway Mobile Source - Helicopter Inflight	00023240	26
		Off-Highway Mobile Source - Local Aircraft Ems.	00023250	37
Gasoline Powered Automobiles	45890	Gasoline Powered Automobiles	00022100	51475
Heavy - Duty Diesel Vehicles	45604	Heavy - Duty Diesel Vehicles	00021400	45609

SIC Name	SIC #	SCC Name	SCC #	Emissions (tonnes)
Heavy - Duty Gasoline Trucks	45601	Gasoline Powered Vehicles - Heavy Duty Trucks	00021200	4585
Light - Duty Gasoline Trucks	45600	Gasoline Powered Vehicles - Light Duty Trucks	00021100	24742
Light - Duty Diesel Trucks	45603	Diesel Powered Engines - Light Duty Vehicles	00021300	822
Motor Cycles	45891	Gasoline Powered Vehicles - Motor Cycles	00021150	173
Marine	45400	Off-Highway Mobile Source - Motorships Dockside	00025110	1167
		Off-Highway Mobile Source - Gasoline Outboard	00025310	26
Off-Road Use of Gasoline	45894	Non-Highway Use of Gasoline	00022100	2190
Snowmobiles	45892	Gasoline Powered Vehicles - Snowmobiles	00022140	30
Railroads	45310	Off-Highway Mobile Source - Diesel Oil - Railroads	00024100	15618
Other Diesel Vehicles	45602	Diesel Powered Vehicles - Agricultural Vehicles	00022210	2852
		Diesel Powered Vehicles - Construction Vehicles	00022220	4013
		Diesel Powered Vehicles - Mining Vehicles	00022230	8157
		Diesel Powered Vehicles - Manufacturing Vehicles	00022240	12094
		Diesel Powered Vehicles - Forestry Vehicles	00022250	8120
		Diesel Powered Vehicles - Public Administration V.	00022260	7999
		Diesel Powered Vehicles - Pipeline Vehicles	00022270	737

SIC Name	SIC #	SCC Name	SCC #	Emissions (tonnes)
VOC Transportation				
Aircraft	45110	Off-Highway Mobile Source - Jet Aircraft	00023110	108
		Off-Highway Mobile Source - Turboprop	00023120	12
		Off-Highway Mobile Source - Piston Engine	00023130	20
		Off-Highway Mobile Source - Helicopters	00023140	2
		Off-Highway Mobile Source - Small Piston	00023150	7
		Off-Highway Mobile Source - Jet Aircraft Inflight	00023210	20
		Off-Highway Mobile Source - Piston Inflight	00023240	638
		Off-Highway Mobile Source - Helicopter Inflight	00023240	22
		Off-Highway Mobile Source - Local Aircraft Ems.	00023250	581
Gasoline Powered Automobiles	45890	Gasoline Powered Automobiles	00022100	60890
Heavy - Duty Diesel Vehicles	45604	Heavy - Duty Diesel Vehicles	00021400	6229
Heavy - Duty Gasoline Trucks	45601	Gasoline Powered Vehicles - Heavy Duty Trucks	00021200	6885
Light - Duty Gasoline Trucks	45600	Gasoline Powered Vehicles - Light Duty Trucks	00021100	36887
Light - Duty Diesel Trucks	45603	Diesel Powered Engines - Light Duty Vehicles	00021300	193
Motor Cycles	45891	Gasoline Powered Vehicles - Motor Cycles	00021150	743
Marine	45400	Off-Highway Mobile Source - Motorships Dockside	00025110	770
		Off-Highway Mobile Source - Gasoline Outboard	00025310	4033
Off-Road Use of Gasoline	45894	Non-Highway Use of Gasoline	00022100	3503
Snowmobiles	45892	Gasoline Powered Vehicles - Snowmobiles	00022140	1700

SIC Name	SIC #	SCC Name	SCC #	Emissions (tonnes)
Railroads	45310	Off-Highway Mobile Source - Diesel Oil - Railroads	00024100	758
Other Diesel Vehicles	45602	Diesel Powered Vehicles - Agricultural Vehicles	00022210	495
		Diesel Powered Vehicles - Construction Vehicles	00022220	370
		Diesel Powered Vehicles - Mining Vehicles	00022230	631
		Diesel Powered Vehicles - Manufacturing Vehicles	00022240	924
		Diesel Powered Vehicles - Forestry Vehicles	00022250	849
		Diesel Powered Vehicles - Public Administration V.	00022260	549
		Diesel Powered Vehicles - Pipeline Vehicles	00022270	60
Tire & Tube Industry	15111	Tire Wear - 4 Wheeled	00026100	81
		Tire Wear - 8 Wheeled	00026200	22
VOC Miscellaneous				
Painting & Decorating	42751	Application of Surface Coating - Trade, Sales Use	00077000	6961
		Application of Surface Coating - Industrial Use	00078200	7014
Dry Cleaning Plants	97211	Dry Cleaning	00071000	5129
Gasoline Fuel Marketing	51111	Diesel & Gasoline Mkting-Refinery Storage Transfer	00027110	2030
		Diesel & Gasoline Mkting-Filling Vehicle Tank	00027111	859
		Diesel & Gasoline Mkting-Station Storage Transfer	00027130	3247
		Diesel & Gasoline Mkting-Vapour Loss at Stations	00027140	419
		Diesel & Gasoline Mkting-Transfer to Cars	00027150	4800
		Diesel & Gasoline Mkting-Spillage at Station	00027160	279
		Bulk Plant Fixed Roof Working Losses	40400294	160
		Pet. Stg.\Bulk Plant\Standing Losses	40400297	168
		Roof TNK Tank Cars/Trucks Gasoline	40600131	328

SIC Name	SIC #	SCC Name	SCC #	Emissions (tonnes)
General Solvent Use	65321	General Solvent Use	00070000	12003
Slash Burning	04120	Slash Burning	00033100	43944

APPENDIX E

EMISSION FORECASTS FOR NOX/VOC

SCENARIO I:

Emission Forecasts (based on EMPR energy forecasts): NOx/VOC

	EMPR Energy Forecasts (PJ) (1)				Greenhouse Gases Inv.			
Sector	1988	2005	1985 (est)	Forecast % Change (1985-2005)	Actual Em. (kT 1985) NOx	Actual Em. (kT 1985) VOC	Forecast Em. (kT 2005) NOx	Forecast Em. (kT 2005) VOC
TRANSPORTATION								
Gas Vehicles	125.1	134.7	123.4	9.2	83.2	110.7	90.9	120.9
Diesel Vehicles	39.0	60.6	35.2	72.0	90.4	10.2	155.5	17.5
Other (2)	78.4	102.0	74.3	37.0	19.9	7.1	27.3	9.7
SUB-TOTAL					193.5	128.0	273.7	148.1
FUEL COMBUSTION								
Residential	129.8	191.1	119.0	60.7	3.6	4.0	5.8	6.4
Commercial	92.1	129.1	79.7	61.9	2.8	0.2	4.5	0.3
Power Generation	23.5	100.7	9.9	922	5.9	0.3	54.1	2.9
SUB-TOTAL					12.3	4.5	64.4	9.6
INDUSTRIAL PROC. (3)	453.7	618.3	423.0	46.2	47.6	58.9	69.6	86.1

APPENDIX E (Cont'd): EMISSION FORECASTS FOR NOX/VOC

SCENARIO I (Cont'd): *Emission Forecasts (based on EMPR energy forecasts): NOx/VOC*

Sector	EMPR Energy Forecasts (PJ) 1988	2005	1985 (est)	Forecast % Change (1985-2005)	Greenhouse Gases Inv. Actual Em. (kT 1985) NOx	VOC	Forecast Em. (kT 2005) NOx	VOC
INCINERATION/MISC.								
Mun./Ind. Incineration				96.3 (4)	0.5	0.1	1.0	0.2
Wood Waste Incineration				-29.0 (4)	2.1	2.4	1.5	1.7
Slash Burning				-35.4 (4)	9.0	43.9	5.8	28.6
Fuel Marketing				9.2 (5)	-	12.4	-	13.5
Dry Cleaning				45.7 (6)	-	5.1	-	7.4
Solvent Use				45.7 (6)	-	12.0	-	17.5
Surface Coatings				45.7 (6)	-	14.0	-	20.4
SUB-TOTAL					11.6	89.9	8.3	48.6
Total					**265**	**281.3**	**416**	**287.8**

(1) Energy forecast data obtained from B.C. EMPR (1991).

(2) B.C. EMPR energy demand forecast data for aircraft, marine, rail, natural gas end use, electricity end use, and LPG vehicles.

(3) Includes LOMEI point sources.

(4) Growth estimates obtained from B.C. EMPR CO_2 Inventory for B.C. (1988) extrapolated to1985.

(5) Assume growth forecast in fuel marketing is equal to energy demand forecast for gas vehicles.

(6) Growth forecast based on population forecast to 2016 prorated to 2005 (B.C. FIN, 1991).

APPENDIX E (Cont'd)
EMISSION FORECASTS FOR NOX/VOC

SCENARIO II:

Emission Forecasts NOx/VOC Management Plan 90-B: NOx

Sector	NOx/VOC Mgt. Plan		Greenhouse Gases Inv.	
	Actual Em. 1985 (kT)	Forecast Change 1985-2005	Actual Em. 1985 (kT)	Forecast Em. 2005 (kT)
TRANSPORTATION				
Cars	46.6	- 58.4	51.5	21.4
Light-duty trucks				
gas	17.3	- 42.8	24.7	14.2
diesel	0.9	+ 100	0.8	1.6
Heavy-duty trucks				
gas	4.8	- 66.7	4.6	1.5
diesel	48.2	- 40.5	45.6	27.1
Off-road diesel				
construction	4.0	+ 5	4.0	4.2
agriculture	2.9	+151.7	2.9	7.2
railroads	16.8	- 20.2	15.6	12.5
other	37.2	+ 18.8	37.1 (1)	44.1
Other	6.7	+ 37.3	6.7 (2)	9.2
SUB-TOTAL	185.4		193.5	141.4
FUEL COMBUSTION				
Residential	3.6	- 8.3	3.6	3.3
Commercial	2.7	+ 7.4	2.8	3.0
Power Generation	3.7	- 67.6	5.9 (3)	1.9
SUB-TOTAL	10.0		12.3	8.2
INDUSTRIAL PROC.(4)				
Industrial Processes	10.7	+ 56.1	45.0	70.2
Other Ind. Fuel Comb	35.2	+ 36.1	2.6	3.5
SUB-TOTAL	45.9		47.6	73.7
INCINERATION/MISC.	11.3	+ 21.2	11.6 (5)	14.03
Total	**252.6**		**265**	**223.3**

(1) Vehicles for mining, manufacturing, forestry, public administration, and pipeline vehicles.

(2) Aircraft, motorcycles, marine vehicles, off road use of gasoline excluding everything under (1), and snowmobiles.

(3) Electric power generation including Burrard Thermal.

(4) Industrial processes and LOMEI point sources. Includes other industrial fuel combustion.

(5) Slash burning (Misc.) and Incineration (wigwam burners, industrial incineration, municipal incineration and Burnaby Incinerator).

SCENARIO II (Cont'd):

*Emission Forecasts NOx/VOC Management Plan 90-B: **VOC***

	NOx/VOC Mgt. Plan		Greenhouse Gases Inv.	
Sector	Actual Em. 1985 (kT)	Forecast Change 1985-2005	Actual Em. 1985 (kT)	Forecast Em. 2005 (kT)
TRANSPORTATION				
Cars	58.3	- 39.1	60.9	37.1
Light-duty trucks				
gas	26.3	- 46	36.9	19.9
diesel	0.2	+ 200	0.2	0.6
Heavy-duty trucks				
gas	6.9	- 82.6	6.9	1.2
diesel	5.2	- 5.8	6.2	5.9
Off-road gasoline	5.2	+ 9.6	3.5	3.8
Other	11.7	+45.3	13.4	19.5
SUB-TOTAL	113.8		128	88
FUEL COMBUSTION				
Fuelwood (Residential)	3.8	+ 31.6	3.8	5.1
Residential/Commerc.	0.3	+- 0.0	0.3	0.3
Power Generation	0.3	+- 0.0	0.3	0.3
SUB-TOTAL	4.4		4.4	5.7
INDUSTRIAL PROC. (1)				
Industrial Processes	14.7	+ 52.4	57.5	87.6
Other Ind. Fuel Comb.	42.7	+ 30.7	1.4	1.8
SUB-TOTAL	57.4		58.9	89.4
INCINERATION/MISC.				
Surface Coatings	21.5	+ 17.2	14.0	16.4
Fuel Marketing	12.4	- 8.1	12.3	11.4
Dry Cleaning	1.6	+ 12.5	5.1	5.8
Solvent Use	30.3	+ 13.2	12.0	13.6
Slash burning	43.9	+ 30.8	43.9	57.5
Other (2)	9.1	+ 26.4	-	-
SUB-TOTAL	118.8		87.3	94.7
Total (3)	**294.4**		**278.6**	**277.8**

(1) Industrial processes and LOMEI point sources. Includes other industrial fuel combustion.

(2) Unclear what Misc. (Other) in NOx/VOC Mgt Plan accounts for.

(3) Excluding Misc. (Other).

APPENDIX E (Cont'd)

SCENARIO III:

Emission Forecasts NOx/VOC Management Plan - Post-Plan: NOx

Sector	NOx/VOC Mgt. Plan Reduction 90-B to post plan (%)	Greenhouse Gases Inv. Act Em. 1985 (kT)	90-B Em. forecast (kT)	Post plan Em. forecast (kT)
TRANSPORTATION (1)				
LDVs	29.3	77.0	37.2	26.3
HDVs	10.2	50.2	28.6	25.7
Off road diesel	1.0	59.6	68.0	67.3
SUB-TOTAL		186.8	133.8	119.3
FUEL COMBUSTION				
Comm./Ind. fuel comb.	18.3	2.8	3.0 (2)	2.5
Residential fuel comb.	9.1	3.6	3.3	3.0
Elect. power gen.	83.3	5.9	1.9	0.3
SUB-TOTAL		12.3	8.2	5.8
INDUSTRIAL PROCESSES	6.0	47.6	73.7	69.3
Total		**246.7**	**215.7**	**194.4**

(1) LDVs - assume to include all cars and light duty trucks; HDVs assume to include all heavy duty gas and diesel trucks; Off-road diesel (see Plan 90-B above).

(2) Only commercial fuel combustion. However, for the post plan emission forecast, the combined reduction estimate for commercial and industrial fuel combustion was applied.

Emission Forecasts NOx/VOC Management Plan - Post-Plan: VOC

Category	NOx/VOC Mgt. Plan Reduction 90-B to post plan (%)	Greenhouse Gases Inv. Act Em. (1985) (kT)	90-B Em. forecast (kT)	Post plan Em. forecast (kT)
TRANSPORTATION				
LDVs	23.7	98.0	57.6	44.0
IND. PROCESS/COMB.	10.3	63.3	95.1	85.3
MISCELLANEOUS				
Vol. Liq. Storage (1)	18.4	12.3	11.4	9.3
Paints/coatings	35.7	14.0	16.4	10.5
Other Solvents Use (2)	21.3	17.1	19.4	15.3
SUB-TOTAL		43.4	47.2	35.1
Total		**204.7**	**199.9**	**164.4**

(1) Assume equivalent to fuel marketing.

(2) Assumed to include the categories dry cleaning and solvent use

APPENDIX F: B.C. EMPR ENERGY DEMAND FORECAST DATA

COMMERCIAL SECTOR ENERGY DEMAND (PJ)

YEAR	DELCCOM	DNGSCOM	DRPPCOM	DTOTCOM	YEAR
1990	42.62 (46.3)	35.84 (38.9)	13.61 (14.8)	92.08	1990
1991	42.92	38.99	12.29	94.22	1991
1992	43.74	41.62	11.64	97.01	1992
1993	44.88	43.47	11.66	99.99	1993
1994	45.76	44.87	12.13	102.75	1994
1995	47.15	45.40	12.77	105.33	1995
1996	48.73	46.71	12.26	107.70	1996
1997	50.48	48.01	11.73	110.19	1997
1998	52.03	49.30	11.12	112.46	1998
1999	53.48	49.71	11.37	114.56	1999
2000	55.12	50.35	11.56	117.04	2000
2001	56.70	51.43	11.23	119.37	2001
2002	58.23	52.58	10.86	121.66	2002
2003	59.80	53.79	10.50	124.11	2003
2004	61.22	55.16	10.18	126.87	2004
2005	62.54	56.68	9.92	129.12	2005
2006	63.90	56.91	11.13	131.95	2006
2007	65.22	58.31	11.00	134.54	2007
2008	66.80	59.80	10.86	137.16	2008
2009	67.81	61.32	10.69	139.83	2009
2010	69.17	62.88	10.49	142.55	2010

Total (Commercial)
Refined Petroleum Products
Natural Gas
Electricity

MNEMONIC	TITLE	SECTO	FUEL	DESCRIPT	UNITS	LAST_A	Y1988	Y1989	Y2005	Y2010
INDUSTRY & MINING										
	CHEMICALS									
DHFOCHE		CHE	HFO	SECONDARY REQTS; HEAVY FUEL OIL; CHEMICALS	PJ	1985	0.61427	0.63989	0.45068	0.43958
DLFOCHE		CHE	LFO	SECONDARY REQTS; LIGHT FUEL OIL; CHEMICALS	PJ	1985	0.03772	0.03703	0.02608	0.02544
DELCCHE	Elec:Chemicals	CHE	ELC	SECONDARY REQTS; ELECTRICITY; CHEMICALS	PJ	1985	4.00000	4.64424	6.37688	6.45882
DNGSCHE	Ngs:Chemicals	CHE	NGS	SECONDARY REQTS; NATURAL GAS; CHEMICALS	PJ	1985	4.30762	4.55348	4.53131	4.51711
	SUB-TOTAL						8.95961	9.87464	11.38495	11.44095
	MINING									
DNGSMIN	Ngs:Mining	MIN	NGS	SECONDARY REQTS; NATURAL GAS; MINING	PJ	1985	6.87541	5.41252	7.82489	8.48297
DDFOMINSE		MIN	DFO	SECONDARY REQTS; DIESEL FUEL; MINING	PJ	1988	10.35780	7.55390	5.02396	5.03051
DELCMIN		MIN	ELC	SECONDARY REQTS; ELECTRICITY; MINING	PJ	1985	10.47270	11.10120	11.46510	10.20870
DLPGMIN		MIN	LPG	SECONDARY REQTS; LPGs; MINING	PJ	1985	0.36972	0.27719	0.19371	0.19392
	SUB-TOTAL									
DLPGNMT		NMT	LPG	SECONDARY REQTS; LPGs; NON-METALLIC	PJ	1985	0.01226	0.01220	0.01393	0.01445
DBGSNMT	Biogas:Cement	NMT	BGS	BIOGAS EXTRACTED FROM RICHMOND MUNICIPAL D	PJ	1988	0.15696	0.15653	0.19094	0.20432
DCACNMT	Coal:Cement	NMT	CAC	SECONDARY REQTS; COKE & COAL; NON-METALLIC	PJ	1985	0.94508	0.94249	1.14965	1.23023
DNGSNMT	Ngs:Cement	NMT	NGS	SECONDARY REQTS; NATURAL GAS; NON-METALLIC	PJ	1985	2.71820	2.71252	3.37237	3.63866
DELCNMT	Elec:Cement	NMT	ELC	SECONDARY REQTS; ELECTRICITY; NON-METALLIC	PJ	1985	0.66400	0.57091	0.72960	0.78798
DPCKNMT		NMT	PCK	SECONDARY REQTS; PETROLEUM COKE; NON-METALL	PJ	1988	0.71000	0.70652	0.80649	0.83702
DDFONMT		NMT	DFO	SECONDARY REQTS; DIESEL FUEL; NON-METALLIC	PJ	1985	0.09334	0.09288	0.10602	0.11004
	SUB-TOTAL						5.29984	5.19405	6.369	6.8227
	REFINING									
DCACSUP	Coal:Mining Own Use	REF	CAC	PRODUCER REQTS; COKE & COAL	PJ	1989	4.01300	5.11088	6.37923	6.73074
DNGSREF	Ngs:Refineries	REF	NGS	SECONDARY REQTS; NATURAL GAS; REFINERY	PJ	1988	1.24537	0.47942	0.55783	0.43598
DMOGSUP		REF	MOG	PRODUCER REQTS; MOTOR GASOLINE	PJ	1989	0.00700	0.22466	0.11776	0.11247
DSGSSUP		REF	SGS	PRODUCER REQTS; STILL GAS	PJ	1989	17.25100	17.25110	11.84630	11.01420
DDFOSUP		REF	DFO	PRODUCER REQTS; DIESEL FUEL	PJ	1989	0.16000	0.47440	0.39088	0.37343
	SUB-TOTAL						22.67637	23.54046	19.292	18.66682
	PRIMARY METALS									
DELCPMT	Elec:Primary Metals	PMT	ELC	SECONDARY REQTS; ELECTRICITY; PRIMARY METALS	PJ	1985	0.69000	0.59217	0.75582	0.75075
DDFOPMT		PMT	DFO	SECONDARY REQTS; DIESEL FUEL; PRIMARY METALS	PJ	1985	0.10090	0.09526	0.03185	-0.01687
DLFOPMT		PMT	LFO	SECONDARY REQTS; LIGHT FUEL OIL; PRIMARY META	PJ	1985	0.05697	0.05056	0.01751	-0.00927
DHFOPMT		PMT	HFO	SECONDARY REQTS; HEAVY FUEL OIL; PRIMARY MET	PJ	1985	0.04129	0.04305	0.01359	-0.00720
DNGSPMT	Ngs:Primary Metals	PMT	NGS	SECONDARY REQTS; NATURAL GAS; PRIMARY METAL	PJ	1985	2.14000	2.02843	2.30691	2.50364
	SUB-TOTAL						3.02916	2.80947	3.12568	3.22105
DHFOXIN		XIN	HFO	SECONDARY REQTS; HEAVY FUEL OIL; OTHER INDUST	PJ	1988	-1.53488	0.09589	0.09589	0.09589
DDFOXIN		XIN	DFO	SECONDARY REQTS; DIESEL FUEL; OTHER INDUSTRIA	PJ	1988	4.35878	12.12810	12.12810	12.12810
DLFOXIN		XIN	LFO	SECONDARY REQTS; LIGHT FUEL OIL; OTHER INDUST	PJ	1988	1.20894	1.37000	1.37000	1.37000
DNGSXINSE	Ngs:Other Ind	XIN	NGS	SECONDARY REQTS; NATURAL GAS; OTHER IND	PJ	1988	12.08380	5.42000	6.87790	7.40945
DLPGXIN		XIN	LPG	SECONDARY REQTS; LPGs; OTHER INDUSTRIAL	PJ	1988	-0.32027	-0.76874	-0.76874	-0.76874
	SUB-TOTAL						15.79637	18.24525	19.70315	20.2347
DNGSXMA	Ngs:Other Manf	XMA	NGS	SECONDARY REQTS; NATURAL GAS; OTHER MANUFA	PJ	1985	16.76250	16.60850	29.37030	34.85090
DELCXMA	Elec:Other Manf	XMA	ELC	SECONDARY REQTS; ELECTRICITY; OTHER MANUFAC	PJ	1985	6.74653	6.69014	16.35380	19.64100
DLPGXMA		XMA	LPG	SECONDARY REQTS; LPGs; OTHER MANUFACTURING	PJ	1985	0.26943	0.27853	0.43950	0.48494
DDFOXMA		XMA	DFO	SECONDARY REQTS; DIESEL FUEL; OTHER MANUFACT	PJ	1985	0.71986	0.74417	1.17424	1.29565
DLFOXMA		XMA	LFO	SECONDARY REQTS; LIGHT FUEL OIL; OTHER MANUF	PJ	1985	0.23272	0.24058	0.19016	0.22941
DHFOXMA		XMA	HFO	SECONDARY REQTS; HEAVY FUEL OIL; OTHER MANUF	PJ	1985	0.16776	0.17343	0.09509	0.12338
	SUB-TOTAL						24.8988	24.73535	47.62309	56.62528
	TOTAL						64.91323	65.66242	87.21969	96.20198

MNEMONIC	TITLE	SECTO	FUEL	DESCRIPT	UNITS	LAST_A	Y1988	Y1989	Y2005	Y2010
DLGRNON		NON	LGR	SECONDARY REQTS; LUBES & GREASES; NON-ENERGY	PJ	1988	4.42100	4.80970	4.97762	5.06198
DASPNON		NON	ASP	SECONDARY REQTS; ASPHALT; CONVERTED @ 44.46TJ	PJ	1988	7.86500	7.97169	8.28447	8.46040
DPCKNON		NON	PCK	SECONDARY REQTS; PETROLEUM COKE; NON-ENERGY	PJ	1989	3.14000	3.64479	4.30480	4.30480
DOTHNON		NON	OTH	SECONDARY REQTS; OTHER NON-ENERGY	PJ	1988	2.58000	4.11000	5.36838	5.44792
	SUB-TOTAL						18.006	20.53618	22.93527	23.2751
	PULP & PAPER									
DELCPAPSE	Elec:Pulp&Paper	PAP	ELC	ELECTRICITY; PULP&PAPER	PJ	1988	37.95790	40.57860	75.65340	80.70320
DDPOPAPSE	DFO:Pulp&Paper	PAP	DFO	SECONDARY REQTS; DIESEL FUEL; PULP&PAPER	PJ	1988	0.46586	0.50275	0.63117	0.66735
DOTHPAP	Biogas&Tall Oil:P&P	PAP	OTH	SECONDARY REQTS; OTHER FUEL; PULP&PAPER	PJ	0	0.75000	0.70965	1.44624	1.55714
GNGSPAP		PAP	NGS	USED TO GENERATE ELEC; NATURAL GAS; PULP&PAP	PJ	1989	3.27739	3.62456	5.97881	6.86152
DLIQPAPSE	Liq:Pulp&Paper	PAP	LIQ	SECONDARY REQTS; PULPING LIQUORS; PULP&PAPER	PJ	1986	131.18500	132.42100	141.67900	143.90700
GHPOPAP		PAP	HFO	USED TO GENERATE ELEC; HEAVY FUEL OIL; PULP&P	PJ	1989	2.89301	3.11588	4.19993	4.40511
DHPOPAPSE	HFO:Pulp&Paper	PAP	HFO	SECONDARY REQTS; HEAVY FUEL OIL; PULP&PAPER	PJ	1986	20.09430	23.38860	18.61820	19.97130
DLPGPAPSE	LPGs:Pulp&Paper	PAP	LPG	SECONDARY REQTS; LPGs; PULP&PAPER	PJ	1988	0.30711	0.32647	0.38572	0.40704
GLIQPAP	Liq:Converted to Elc	PAP	LIQ	USED TO GENERATE ELEC; PULPING LIQOUR;PULP&PA	PJ	1986	5.48015	6.11650	6.78823	6.92572
DNGSPAPSE	Ngs:Pulp&Paper	PAP	NGS	SECONDARY REQTS; NATURAL GAS; PULP&PAPER	PJ	1986	23.51890	23.41220	45.15870	47.33160
DCACPAP2	Coal:Pulp&Paper	PAP	CAC	SECONDARY REQTS; COKE & COAL; PULP&PAPER; RE	PJ	1988	0.24612	0.09376	0.23544	0.23670
	SUB-TOTAL						226.17574	234.28997	300.77284	312.97368
DNGSPCM	Ngs:Petrochemicals	PCM	NGS	FEEDSTOCK REQTS; NATURAL GAS	PJ	1988	18.66200	24.09800	25.13490	25.13490
	SUB-TOTAL						18.662	24.098	25.1349	25.1349
	REDIDENTIAL/AGR.									
DLPORES	LPO:Residential	RES	LPO	SECONDARY REQTS; LIGHT FUEL OIL; AGRICULTURAL	PJ	1989	11.69400	11.55110	3.42540	2.90353
DLPGRES	LPGs:Residential	RES	LPG	SECONDARY REQTS; LPGs; RESIDENTIAL	PJ	1989	1.36500	1.33770	0.55780	0.46465
DCACRES	Coal:Residential	RES	CAC	SECONDARY REQTS; COKE & COAL; RESIDENTIAL	PJ	1989	0.00600	0.00588	0.00426	0.00385
DELCRES	Elec:Residential	RES	ELC	SECONDARY REQTS; ELECTRICITY; RESIDENTIAL	PJ	1989	43.35300	44.80680	63.97590	68.29650
DNGSRES	Ngs:Residential	RES	NGS	SECONDARY REQTS; NATURAL GAS; RESIDENTIAL	PJ	1989	71.78000	78.34070	119.34300	129.25300
DDPORES	DFO:Residential	RES	DFO	SECONDARY REQTS; DIESEL FUEL; AGRICULTURE	PJ	1989	1.59900	3.28725	3.83746	4.01434
	SUB-TOTAL						129.797	139.32943	191.14382	204.93587
	PRODUCER REQUIREMENTS									
	POWER GENERATION									
DPCKSUP		SUP	PCK	PRODUCER REQTS; PETROLEUM COKE	PJ	1989	1.90200	1.98949	1.89706	1.89709
DHPOSUP		SUP	HFO	PRODUCER REQTS; HEAVY FUEL OIL	PJ	1989	0.25400	0.34212	0.39366	0.37616
DLPOSUP		SUP	LPO	PRODUCER REQTS; LIGHT FUEL OIL	PJ	1989	0.00500	0.02081	0.01400	0.01338
DELCSUP	Elec:Losses	SUP	ELC	PRODUCER REQTS; ELECTRICITY	PJ	1989	17.51900	18.19300	28.19120	30.60770
GDPOTOT	DFO:Converted to Elc	SUP	DFO	USED TO GENERATE ELEC; DIESEL FUEL; TOTAL	PJ	1989	2.52000	2.54662	3.03488	3.21452
DNENSUP		SUP	NEN	PRODUCER REQTS; NON-ENERGY PRODUCTS	PJ	1989	0.07500	0.54625	0.24488	0.24488
GELCUTL	Elec:From Utl(Thermal)	SUP	ELC	THERMAL GENERATION; ELEC; UTILITIES	PJ	1990	0.30000	15.10000	26.65280	26.70540
DHOGTOTSE	Hog:Secondary Reqts	SUP	HOG	SECONDARY REQTS; HOG FUEL; TOTAL	PJ	1986	67.73400	68.71170	82.35820	84.33480
DNGSPIP	Ngs:Pipelines&Losses	SUP	NGS	PIPELINE USE; NATURAL GAS	PJ	1989	14.68600	17.47630	29.75980	32.24700
GNGSWKPL		SUP	NGS	USED TO GENERATE ELEC; NATURAL GAS; WKPL REQ	PJ	0	0.00000	0.00000	6.62256	6.62256
GNGSBCH	Ngs:To Elc by Utl	SUP	NGS	USED TO GENERATE ELEC; NATURAL GAS; BC HYDRO	PJ	1990	0.89900	44.03900	40.25800	40.25800
	SUB-TOTAL						105.894	168.96529	219.42704	226.52149
DLPGSUP	RPPs:Ngs Plant Own Use	NGS	LPG	PRODUCER REQTS; LPGs	PJ	1989	0.31800	0.31275	0.26470	0.25038
	SUB-TOTAL						0.318	0.31275	0.2647	0.25038
	TOTAL						106.212	169.27804	219.69174	226.77187

MNEMONIC	TITLE	SECTO	FUEL	DESCRIPT	UNITS	LAST_A	Y1988	Y1989	Y2005	Y2010
TRANSPORTAION										
	AIR									
DAVGAIR	Air:Aviation Gasoline	AIR	AVG	SECONDARY REQTS; AVIATION GASOLINE; AIR	PJ	1989	1.16900	1.24800	1.75564	1.98635
DAVTAIR	Air:Jet Fuel	AIR	AVT	SECONDARY REQTS; AVIATION TURBO; AIR	PJ	1989	29.41500	33.38790	45.38440	52.30220
	SUB-TOTAL						30.584	34.6359	47.14004	54.28855
	ROAD									
DDFOROD	Road:DFO	ROD	DFO	SECONDARY REQTS; DIESEL FUEL; ROAD	PJ	1989	39.02200	44.40000	60.56330	64.25930
DMOGROD	Road:Gasoline	ROD	MOG	SECONDARY REQTS; MOTOR GASOLINE; ROAD	PJ	1989	125.07200	129.30200	134.74500	136.69100
DLPGROD	Road:LPGs	ROD	LPG	SECONDARY REQTS; LPGs; ROAD TRANSPORT	PJ	1989	5.05200	5.12500	6.29559	6.56752
	SUB-TOTAL						169.146	178.827	201.60389	207.51782
	RAIL									
DDFORAL	Rail:DFO	RAL	DFO	SECONDARY REQTS; DIESEL FUEL; RAIL	PJ	1989	12.52200	12.92030	13.71210	14.15230
	SUB-TOTAL						12.522	12.9203	13.7121	14.1523
	MARINE									
DDFOMAR	Marine:DFO	MAR	DFO	SECONDARY REQTS; DIESEL FUEL; MARINE	PJ	1989	13.32000	13.65140	17.76520	18.21110
DHFOMAR	Marine:HFO	MAR	HFO	SECONDARY REQTS; HEAVY FUEL OIL; MARINE	PJ	1989	15.74000	16.69740	21.39750	23.05120
	SUB-TOTAL						29.06	30.3488	39.1627	41.2623
DELCTRN	Elec:Transport	TRN	ELC	END USE; ELECTRICITY; TRANSPORTATION; TOTAL	PJ	1988	0.36128	0.32224	0.39051	0.41109
DNGSTRN	Ngs:Transport	TRN	NGS	END USE; NATURAL GAS; TRANSPORTATION; TOTAL	PJ	1986	0.85900	0.92682	1.57537	1.70147
	SUB-TOTAL						1.22028	1.24906	1.96588	2.11256
	TOTAL						242.53228	257.98106	303.58461	319.33353

MNEMONIC	TITLE	SECTO	FUEL	DESCRIPT	UNITS	LAST_A	Y1988	Y1989	Y2005	Y2010
	WOOD PRODUCTS									
DNGSWOD	Ngs:Wood	WOD	NGS	SECONDARY REQTS; NATURAL GAS; WOOD PRODUCT	PJ	1985	13.90640	14.05180	15.22400	15.23460
DLFOWOD		WOD	LFO	SECONDARY REQTS; LIGHT FUEL OIL; WOOD PRODUC	PJ	1985	0.12743	0.09499	0.02469	0.01679
DLPGWOD		WOD	LPG	SECONDARY REQTS; LPGs; WOOD PRODUCTS	PJ	1985	0.75139	0.60082	0.14977	0.10184
DDFOWOD		WOD	DFO	SECONDARY REQTS; DIESEL FUEL; WOOD PRODUCTS	PJ	1988	2.00000	1.83971	0.42941	0.29197
DELCWOD	Elec:Wood	WOD	ELC	SECONDARY REQTS; ELECTRICITY; WOOD PRODUCTS	PJ	1985	11.27000	10.92240	12.18950	12.15290
	SUB-TOTAL						28.05522	27.50972	28.01737	27.7981
GELCIND	Elec:From Ind(Thermal)	IND	ELC	THERMAL GENERATION; ELEC; INDUSTRIAL	PJ	1988	9.65455	9.82669	19.12230	20.31900
	SUB-TOTAL									
GHOGTOT	Hog:Converted to Elc				PJ		2.98095	3.31164	13.57420	13.67880
DCACXIN	Coal:Other Ind		CAC	SECONDARY REQTS; COKE & COAL; OTHER IND	PJ	1988	2.53534	2.53578	2.53578	2.53578

APPENDIX G

Summaries of Relevant Air Quality Management Studies

Section 5.2 of the main report summarized a number of key comprehensive air quality management plans for other jurisdictions. In this appendix, other relevant studies are discussed. These studies include local management plans (e.g., GVRD, City of Vancouver) as well as sector-specific investigations.

The GVRD Air Management Plan -- Stage I

The purpose of the GVRD Air Management Plan is to ensure that current and future industrial, commercial, and residential activities in the GVRD take place in a manner that avoids degradation of air quality and will meet current and future air quality objectives and standards. Stage I addresses and evaluates the available emission inventory information, assesses air quality trends and current quality, identifies issues and concerns, and provides recommendations for emission control strategies and completion of the further stages of the Plan (defining resources required, cost-benefit assessment of control options, and selection of control methods).

Key conclusions and recommendations related to NO_x and VOC are:

- the 1985 GVRD emissions inventory should be updated, and improved every five years;
- the B.C. Ministry of the Environment and Environment Canada should be encouraged to implement an advanced photochemical model (the Urban Airshed Model) for use cooperatively with the GVRD;
- expanded monitoring of VOCs should be implemented year-round at regional stations;
- woodstove emissions and open burning should be assessed regarding air quality and visibility and possible control measures should be investigated;
- the existing air quality episode management plan should be expanded and include definitions of possible control actions;
- strategies for controlling obvious sources of VOC emissions should be implemented based on available information. These measures include implementing a vehicle inspection and maintenance program;
- air management planning and transportation planning within the GVRD should be integrated.

Specific VOC control options using known technology were identified:

- Motor vehicles:
  - I/M program
  - Lower gasoline RVP
  - Stricter emissions standards or fuel efficiency
  - On-board emissions controls
  - Alternative fuels

- Transportation systems:
  - Public transit improvements
  - Traffic management (e.g., increased occupancy)
  - Growth and land use management
  - Vehicle use management
  - Stricter emissions standards for air, rail, water

- Petroleum production:
  - Gas transfer emissions
  - Waste water emissions
  - Process emissions
  - Product storage emissions
  - I/M program for fugitive emissions

- Surface coatings and solvents:
  - Substitutes for architectural and other coatings
  - Substitutes and controls for clean up and degreasing
  - Control in dry cleaning and printing
  - Substitutes for consumer products

- General:
  - Waste recycling
  - Energy conservation
  - Energy pricing and subsidy incentives

City of Vancouver Task Force on Atmospheric Change

The City of Vancouver Task Force on Atmospheric Change recommendations are related to three targets:

- Phase out of ozone-depleting chemicals within the City by the year 1995;
- Immediate reduction of sulphur dioxide and methane emissions;
- 20% reduction of 1988 CO_2 levels by 2005, and reduction of "related atmospheric pollutants" to federally acceptable levels.

The latter objective includes measures that will affect NO_x and VOC. Some of the means used to reduce these pollutants are to reduce the number of automobile trips in the City and region, increase opportunities for non-auto travel, and reduce use of gasoline and diesel fuel in conventional buses,

autos, and trucks.

Specific recommendations related to transportation and traffic management are:

- traffic management (trip reduction) by-law that specifies responsibilities of the City, employers, employment complexes, and developers for reasonable efforts in implementing trip reduction and transportation management projects (e.g., require employers of 25 or more to achieve a participation rate of 50% of employees or more in commuting alternatives or alternative work hours);
- parking to favour high-occupancy vehicles (preferential rates, etc.);
- make bicycling a better alternative (require parking, protected routes, etc.);
- short-term emission reduction measures (restrictions of occupancy on certain streets and hours);
- road pricing to fund and improve public transit (program of fees and permits to encourage high occupancy; improved transit, alternative bus fuels, etc.);
- encourage telecommuting as an alternative;
- monitor emissions and transportation subsidies.

There are also land use planning measures mainly related to increasing residential density close to work areas, revising zoning to allow more mix of residential and work areas, etc. with the aim of reducing commuting trips and lengths.

City Council has agreed in principle to set fleet fuel efficiency standards to very low levels (4.7 litres/100 km; or the California Air Resources Board standard). The traffic management by-law was approved, as were many of the other transportation and land use recommendations, either outright or in principle, often with requirements for further study by City officials.

GVRD Vehicle Inspection and Maintenance (I/M) Program

In October of 1989 a Task Force recommended that the various government agencies establish agreement on their respective roles in any I/M program. Such a program was seen to be a cost-effective means of ensuring that vehicles continue to meet federal emissions standards. (Studies have shown that many vehicles do not attain these standards as they age.) An I/M program is estimated to achieve annual reductions of 94,100 tonnes of CO (30% of total vehicle emissions), 6,400 tonnes of hydrocarbons (15% of total vehicle emissions), and 800 tonnes of NO_x (5% of total vehicle emissions).

Study of programs in other jurisdictions suggests that the average test fee would be about $15 per year, and the average cost to owners of associated repairs would be approximately $50, representing a cost of about $465 per tonne ($NO_x/CO_2$ equivalent) reduced. Some of the owner cost would be made up through better fuel efficiency. California results suggest cost per ton of VOC and NO_x to be about $1.35 per ton.

A centralized system (central government facilities) is strongly recommended as being far more effective than a decentralized one (local garages do the tests after operator training). Many specific program designs and standards are discussed.

Vancouver Oxidants Study: Control Technology and Options for VOC Emissions from Gasoline Marketing

Various specific technical solutions are discussed for control of VOC from:

- gasoline storage;
- bulk transfer of gasoline;
- motor vehicle refuelling;
- volatility of gasoline due to high Reid Vapour Pressure (RVP), especially in summer months; and
- other toxic emissions.

The report goes into great detail about techniques associated with various types of storage tank, transfer method, etc., and various scenarios are proposed. The most important sources of VOC emissions were found to be fixed roof tanks, bulk loading of trucks at terminals, service stations, and bulk plant deliveries.

Cost effectiveness was estimated to be:

Measure	Annual reduction (tonnes)	$/tonne VOC
Fixed roof tanks	347	(110)
Truck terminals	1,051	80
Bulk plants	57	190
Service stations:		
- Deliveries	1,421	340
- Refuelling	1,057	4,000

Control of VOC emissions from barges and ships could not be costed due to lack of data.

GVRD Fleet Emission Reduction Study

The purpose of this report was to recommend options for reducing emissions from the GVRD and member municipality vehicle fleets.

It was recommended that the GVRD develop a 5-year plan to set the following objectives:

- Reduce vehicle emissions, recognizing the importance of HC and NO_x on ozone.
- Reduce greenhouse gases by maximizing fuel efficiency of fleet vehicles, and by promoting car pooling, good driving habits, and use of public transportation.
- Set limits on total fleet exhaust and evaporative emissions per year.

- Minimize emissions from off-road machinery and from vehicles using auxiliary equipment.

Strategies include:

- Purchasing vehicles with maximum fuel efficiency, and especially considering emission characteristics during purchase. Energy-consuming options such as air conditioners and high performance engines would be avoided. It was recognized that different fleets had different operating requirements, preferred fuel types, etc., and that emissions targets, rather than specific technologies, should be agreed upon by the various fleet managers.

- Promoting driver focus on fuel economy and setting up a fleet fuel consumption database. This database would also include information on mileage driven, emission specifications, and emission test results for fleet vehicles.

- Reducing the number of non-essential journeys.

- Establishing emission control maintenance and repair procedures, as well as measures to minimize evaporative losses. The I/M system would include vehicle inspection every six months.

- Measuring emissions from fleet vehicles using the proposed provincial system.
- Purchasing optimum gas and diesel fuel formulations based on Environment Canada test data.

- Maintaining a "watching brief" on alternative fuels. (It was thought that the tradeoffs involved in use of these fuels needed further study.)

- Rigorously overhauling used fleet vehicles prior to sale to the public, ensuring a low emissions level.

The estimated impact of these measures are:

- If all GVRD vehicles met new vehicle emission standards, annual HC production would be reduced to about 42% of present fleet levels, NO_x would increase by 11%, and CO would fall to 72% of current fleet levels.

- If all fleet vehicles met proposed 1995 California standards, annual HC production would be about 22% of current levels, NO_x would fall to 58% of the present level, and CO to 37% of current levels.

It was also suggested that the GVRD promote early acceptance of the entire 1995 California Emissions Standards.

No costs were discussed.

Ontario: Reduction of energy use and emissions in Ontario's transportation sector

A 1991 report for the Ontario ministries of energy, environment, and transportation considered opportunities to reduce emissions and energy use in the transportation sector. Emissions created by vehicle use were taken into account, but emissions from energy production and distribution were not considered, nor were direct emission control technologies. In addition, because of existing commitments to reduce "conventional automotive pollutants", the study concentrated only on opportunities to reduce CO_2 emissions through increased energy use efficiency. Thus the measures identified do not include explicit consideration of NO_x and VOC, although reductions of these pollutants were calculated.

Eight types of energy saving measures are discussed:

- fuel efficiency achieved through standards
- increased use of transit
- economic instruments, including "carbon taxes" and "gas guzzler" taxes
- land use planning changes to reduce the need for transportation
- traffic management measures to reduce congestion and speed up traffic flow
- vehicle inspection and maintenance programs
- incentives for substituting communications for transportation
- regulatory restrictions of travel demand

The potential contribution to energy or emission reductions of alternative fuels and bicycling were assessed, but the potential was found to be very small.

Measures are categorized into regulatory, economic, and mixed strategies for meeting four scenarios with different levels of energy and emission reductions. Various types of costs and benefits are discussed for the measures and impact on emissions of CO_2, CO, SO_2, NO_x, VOC and particulates estimated. The report represents a comprehensive examination of emission control measures for Ontario's transportation sector, although discussion of non-monetary barriers to implementation are not considered in detail.

APPENDIX H

ALTERNATIVE FUELS

Alternative fuels have frequently been cited as one method to improve urban air quality. In this appendix a brief overview of the literature is presented. The alternatives considered are compressed natural gas, propane, alcohols (mainly methanol because of ease of production), liquid petroleum gas, and electricity. Each is discussed below.

Fuel Characteristics

Compressed natural gas (CNG): CNG vehicles can be fuelled from either a CNG equipped service station or from a home compressor using the existing CNG supply for home heating. CNG vehicles have several advantages compared to gasoline vehicles, including a lower likelihood of burning or exploding following a crash, the possibility of lower operating costs (sources disagree somewhat about this; it may be true only for high-mileage vehicles), and lower emissions. It is essentially a non-toxic fuel.

Disadvantages include: natural gas must be compressed for vehicle use -- the costs of compression facilities are about $25,000 for a commercial service station and about $2,500 for a home compressor (which will also require yearly servicing); high vehicle conversion costs (about $1,500 - 2,000 per vehicle); about 10% less power than gas engines vehicles for converted vehicles; and low range (only about one third that from the same amount of gasoline). The lower cost per litre of fuel would, however, eventually reduce operating costs. Diesel vehicles would require a prohibitively large fuel tank weighing about 1,500 lbs. to give range equivalent to a 55 gallon diesel tank.

Using current technology (ie, including retrofits to gas engines and dual fuel engines), it appears that -- compared to spark ignition gas engines -- CNG automobiles would produce about half the reactive VOC emissions, about the same NO_x levels, one-half to one-eighth the CO levels, and about 5 - 30% less CO_2. Some sources indicate that dual fuel vehicles will not improve on gas engines regarding ozone formation.

Dedicated CNG technology (i.e., engines designed specifically for CNG) would probably reduce reactive VOC emissions to 25% of less of those from gas engines, reduce NO_x by about 30%, and reduce CO to very low levels. It should be noted, though, that NO_x levels are strongly dependent on engine operating characteristics and catalyst type: some references indicate that considerably higher NO_x levels are very possible and that fully effective catalysts have not yet been developed. Unburned methare will also contribute to the greenhouse effect.

Using CNG in diesel engines should reduce particulates. Carbon monoxide emissions will probably not be reduced but are already low. NO_x emissions, however, may increase or decrease depending on engine type and load. VOC emissions should be much lower than those from conventional diesels.

CNG engines also produce higher formaldehyde emissions than gas vehicles. Catalysts will probably be required to deal with these emissions (which may be carcinogenic) as well as to reduce

unburned methane. Data on catalyst efficiency and durability are lacking at present.

Different sources indicate substantially different emission rates. Some manufacturers of prototype retrofit kits claim very low levels of CO and reactive hydrocarbons, but to date these are not available on a commercial basis.

Methanol: Methanol can be used either neat (100% methanol) or as M85 (85% methanol and 15% gasoline to improve cold starting performance).

Methanol use may lower emissions. Current technology engines (including dual fuel engines) using M85 fuel produce about the same reactive VOC as gas engines, 10% less NO_x, and about the same CO. In other words, there is only a small improvement in ozone-causing emissions. Dedicated engines running on neat methanol may produce only 25% as much VOC (some sources indicate zero hydrocarbons) and 10% as much CO; NO_x will be about the same as gas engines. Evaporative emissions will also be low.

Various sources differ considerably in their emission estimates. The figures above are from a report dated 1990. Another report dated 1988 indicates substantial variation of in-use vehicle emissions depending upon the size of engine (four cylinder cars produced about twice the CO and NO_x of eight cylinder vehicles) and the particular fleet tested (one fleet produced about almost twice the emissions of the other). Overall these tests indicated that M85 eight cylinder vehicles produce less hydrocarbons than gas autos, about the same NO_x, and 1-3 times the CO.

Methanol has several disadvantages. It is toxic: about 20 times as toxic as gasoline. Ingestion of one ounce of methanol will cause blindness; two ounces is fatal. Absorption through the skin of large amounts can cause equally serious problems, although small spills will only cause burning and rashes. Methanol fires of spilled fuel are very difficult or impossible to see, causing a significant safety hazard during refuelling. Engines suffer from poor cold starting, poor lubrication (gas acts as a lubricant to the pistons, but methanol is poor at this), and produce four to eight times the aldehyde emissions of gas engines (aldehydes are photoreactive, cause eye irritation, and may be carcinogenic). These problems are probably solvable but the cost is not yet known. Reducing aldehydes and other pollutants will likely require catalysts; the durability of these is unknown. Fuel tanks for neat methanol would have to be twice the size of gas tanks and there is essentially no existing methanol infrastructure.

Emissions from the production of methanol from gas-based plants will be about equal to that of oil refineries, but production from coal-based plants will produce higher levels of pollutants.

In diesel engines, spark-assist will likely be necessary. Such engines will have energy consumption roughly equal to conventional engines, lower NO_x and low (or zero) particulates. Dual fuel vehicles will also share these characteristics. Proper ignition and lubrication may necessitate fuel additives: current additives would drive fuel operating costs to three times that of conventional engines.

Gasohols: Gasohols are made by blending gasoline with methanol (eg, M85) or ethanol. M85 was discussed above. Ethanol blends in older cars would produce about 4% less CO_2, 30% less CO, 15% higher NO_x, and 5% higher hydrocarbons, according to Environment Canada. Newer cars with 3-way catalysts burning gasohols would produce emissions indistinguishable from burning gasoline.

Liquid petroleum gas (LPG): The use of LPG requires only minor engine modifications. In Europe, vehicles are usually dual fuel and conversions are encouraged through tax incentives. Dual fuel vehicles have non-methane organic gas emissions of about half that produced by gas engines. Dedicated LPG engines would probably reduce ozone production from this pollutant to about 20% of that from gas engines. LPG dual fuel engines can produce high NO_x levels, however, almost twice that of gas engines; dedicated engines would likely reduce this to 60% of gas engine levels.

LPG can also be used in diesel engines, where it produces somewhat higher fuel consumption levels, but lower emissions and noise.

Overall, it appears that dual fuelled vehicles would be about the same as gas autos at ozone formation, but dedicated vehicles might be notably better.

LPG engines emit very low levels of CO.

Propane: Propane is similar to CNG as a fuel, but has the advantage of being more easily compressed and stored. Propane vehicles have disadvantages of high conversion costs (about $1,800 per vehicle), somewhat lower range (about 25% less than gas for fuel injected engines), and fire/explosion hazard if the fuel leaks. Because of safety considerations, it may be more suitable for fleet purposes, especially in rural areas.

Propane vehicles have overall lower operating costs since propane costs much less than gasoline. There is a good refuelling infrastructure in the GVRD but few refuelling stations in the City of Vancouver (i.e., refuelling stations in the GVRD are concentrated in the outlying areas, with few stations located in the City itself). Propane is a by-product of natural gas, and there is enough supply for roughly 4-5 times as many propane vehicles as now use it.

A recent test of a propane vehicle indicates in-use emissions of non-methane HC to be about the same as that from a gasoline engine, NO_x to be almost twice as high, CO to be roughly the same, and direct CO_2 production to be slightly lower. Because of the different composition of VOC gases, however, the ozone producing capability of the propane engine exhaust was estimated to be only about 60% that from gasoline engines even though the propane vehicle created more NO_x pollution.

Variable aromatic content gasoline: When the aromatic content of gas was varied from 10-30%, it was found that VOC decreased but olefins increased. Since each has about the same reactivity, total ozone production would not be affected.

Reformulated gasolines: These are "designer" gasolines that have been blended for specific applications (eg, one type might be for high ozone areas, another for high CO regions). Data from oil companies indicate possible changes to pollutants from newer vehicles in the area of +5% to -20% depending on pollutant and gas blend. Often, however, decreasing one pollutant increases another somewhat. Older vehicles may also benefit from such blends, but the direction of change may be opposite to that for newer vehicles.

Electricity: Electricity can be produced in vehicles from batteries or fuel cells. Both power sources have the advantage of producing almost no emissions of consequence.

Batteries, however, are very heavy (roughly half a ton), bulky, expensive (a van would cost about $60,000) and provide only about 60-100 miles of freeway range before they must be plugged in for "refuelling". Some designs can provide top speeds of only about 70 kph. The generation of electricity additionally may cause pollution, especially if from coal-fired plants, while hydro plants have their own set of associated environmental problems.

Fuel cells have potential but are severely constrained by the difficulties of storing the hydrogen they convert to electricity: hydrogen storage tanks of all types are very bulky and heavy, and there is currently no reason to think this can be improved significantly.

Conclusions

The most significant conclusion drawn from this review of the literature is that various sources often disagree as to the emissions resulting from these fuels. This is especially true in terms of the absolute amounts of pollutants formed, but the relative amounts compared to those from conventional engines are also often different. Based on the review, estimates can differ by as much as a factor of six. In addition, some studies consider tailpipe emissions only, while others include evaporative losses. Some sources quote emissions only in terms of grams per mile, while others estimate the amount of ozone that will be produced from NO_x and/or HC.

Such ozone estimates not only depend on the emission level of the pollutants, but also on the relationship assumed for production of ozone from the pollutant. In the case of HC, ozone production varies according to the exact composition of the many compounds that are included in this general classification (each of which has a different ozone production ability), and this in turn varies according to the type of fuel burned and the specific engine technology used. In the case of NO_x, ozone is not related to the levels of this gas in a simple manner, so estimating ozone levels is very difficult.

Overall it is clear that several measurement problems must still be overcome, particularly regarding tests of in-use vehicles rather than "test bed" engines, the changes that occur over the lifespan of the engines, and the variations caused by specific engine and emission control system characteristics.

There are a few studies that attempt to compare the liquid alternative fuels to gasoline with regard to pollutants on the basis of actual in-use vehicle emissions or computer models that use in-use emissions data and fleet composition data to estimate total fleet emissions. In general, these studies indicate that CNG, propane, and LPG all have the potential to reduce ozone levels, while simultaneously reducing direct CO_2 emissions by a small amount compared to using gasoline. In most studies, this is accomplished through reduction -- sometimes great reduction -- of the VOC levels. NO_x levels from the liquid alternative fuels, on the other hand, often are only somewhat lower -- or even considerably higher -- than those emitted by conventional gasoline engines.

M85 does not appear to be as good a candidate for reducing the greenhouse effect. Studies that show it to be better than gasoline in terms of reactive emissions indicate it is only slightly better, and several studies show it to be worse.

In summary, the evidence on alternative fuels, as they relate to NO_x/VOC emissions, is not conclusive. Although many of the studies showed a decrease in VOC emissions, NO_x emissions could be higher or lower than gasoline engines. Combined, it is not possible to definitively

conclude that alternative fuels will consistently provide benefits in the management of NO_x/VOC emissions.

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